Introduction

The project that I originally selected to research for the OC 3570 course was based on remote sensing applications of the marine boundary layer and their verification with actual observed conditions. Unfortunately, overcast conditions during the entire second leg of the cruise limited both useful data from the CIRPAS aircraft and satellite observations. Plan 'B' was therefore executed with the following results.

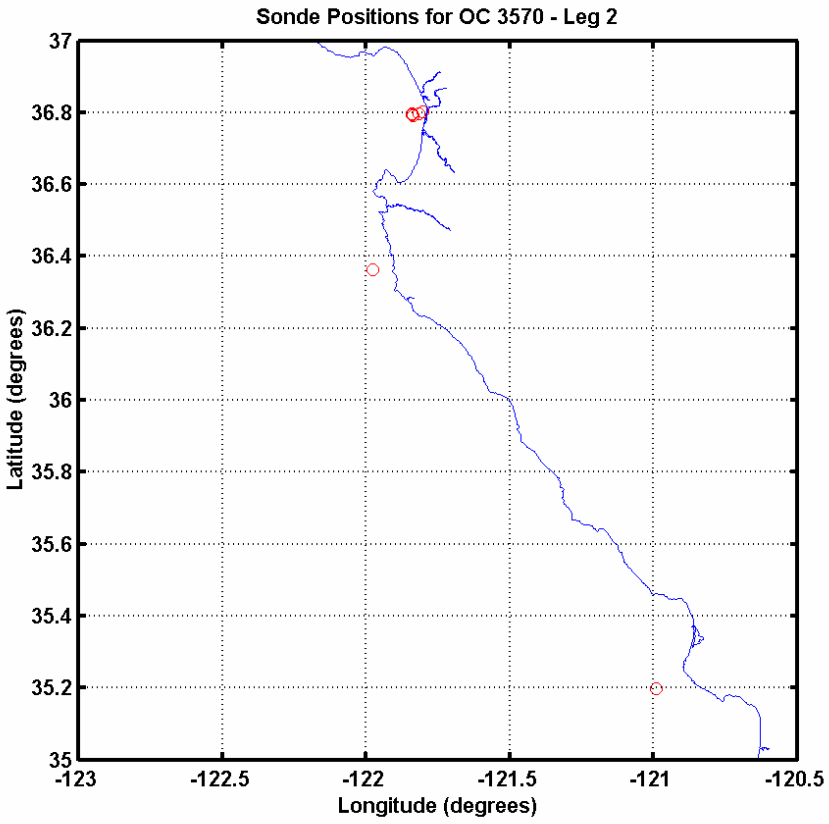
This report will explore, compare and contrast the radio-sonde observations collected during the cruise with MM5 numerical model runs hosted by the Naval Postgraduate School Department of Meteorology. The intent of this endeavor is to explain differences between observation and forecast while exploring why these differences exist and to familiarize myself with the weaknesses of MM5 in the marine boundary layer.

Project Overview

The radio-sonde data consisted of sondes launches 15 through 24 (excluding 21 due to failure). The locations of sonde launches are noted below as well as depicted on the map provided.

Sonde	Lat	Long	Time(GMT)
Sonde15	35-11.93	120-59.39	03 07 24 0405
Sonde16	36-21.76	121-58.64	03 07 25 1807
Sonde17	36-47.47	121-50.22	03 07 25 2345
Sonde18	36-47.88	121-49.06	03 07 26 1758
Sonde19	36-47.86	121-49.02	03 07 26 2341
Sonde22	36-47.56	121-50.42	03 07 27 1802
Sonde23	36-47.66	121-50.45	03 07 27 2348
Sonde24	36-48.12	121-48.18	03 07 28 1808

The type of radio-sonde used for the experiment was RS8Q-15L. The sondes where configured with 100 gram balloons and an improved orifice such that profiles allowed the sensor to make measurements on ascending leg through the boundary layer and then again on a descending leg. This descending leg provided additional information and redundant verification in many cases because of the light wind conditions that existed. From measurements the following parameters could be derived; wind speed (m/s), direction (deg), temperature (C), dew point (C), relative humidity (%), pressure (hPa), height above MSL (m), ascent rate (m/s), RI, MRI, and vapor pressure.

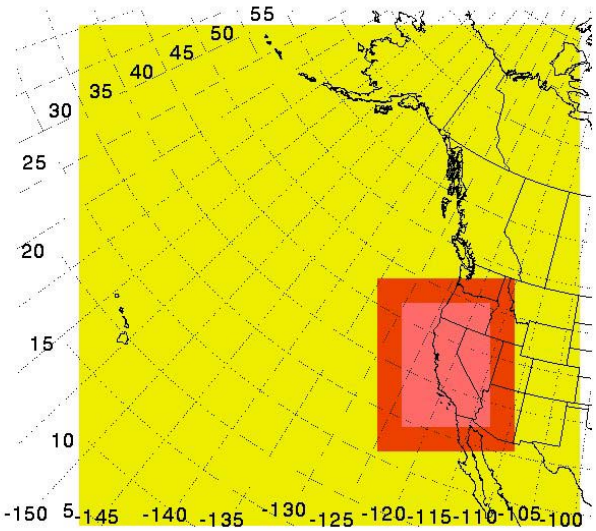


For the model portion of the project, the MM5 mesoscale model was used to provide synthetic sondes for comparison with the actual measured environment. Developed at Penn State and NCAR, it is a popular research tool used at several universities and government laboratories. The MM5 is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. Specifically, the multiple-nest capability and non-hydrostatic dynamics allows the model to be used at a few-kilometer scale, providing a valuable tool for research purposes.

Since MM5 is a regional model, it does require initial conditions as well as lateral boundary conditions therefore must be couple with global models and other regional models to use their output either as first guess for objective analysis, or as lateral boundary conditions. To produce lateral boundary condition for a model run, gridded data is needed to cover the entire time period that the model is integrated. The types of MM5 initializations for each of the simulations corresponding to the July 2003 ship cruise are:

1200 UTC 24 JUL warm start (MM5), LBCs- 1.0deg AVN
0000 UTC 25 JUL warm start (MM5), LBCs- 1.0deg AVN
1200 UTC 25 JUL warm start (MM5), LBCs- 1.0deg AVN
0000 UTC 26 JUL warm start (MM5), LBCs- 1.0deg AVN
1200 UTC 26 JUL warm start (MM5), LBCs- 1.0deg AVN
0000 UTC 27 JUL warm start (MM5), LBCs- 1.0deg AVN
1200 UTC 27 JUL warm start (MM5), LBCs- 1.0deg AVN
0000 UTC 28 JUL warm start (MM5), LBCs- 1.0deg AVN
1200 UTC 28 JUL warm start (MM5), LBCs- 1.0deg AVN

A "warm start" is one that was initialized from a MM5 12-h pre-forecast, whereas a "cold start" is one that was initialized using a coarse (AVN or NOGAPS) forecast. There were no cold starts during this period. Also, lateral boundary conditions (LBC) indicates what was used on the MM5 outermost domain. 2.5deg AVN is coarse both in the horizontal and vertical, whereas 1.0deg AVN (GFS) is finer in both dimensions, but certainly not down to the resolution of the MM5 innermost domain (12-km grid spacing).



The model data that I retrieved from the synthetic soundings included u (m/s), v (m/s), w (m/s), T (K), RH (%), P (mb), and Z (m). For direct comparison with the radiosonde data I did profiles of temperature and dew point temperature in Celsius versus height. Dew point was calculated with the following formula:

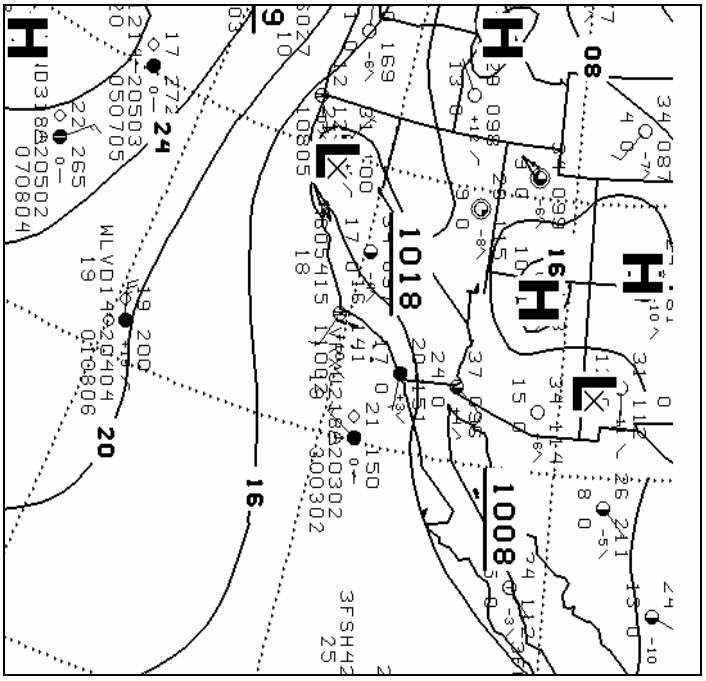
Temp Dew Point (K) = Temp (K)/(1- Temp (K)* 1.84e-4 * log (Rel. Humidity))

Analysis

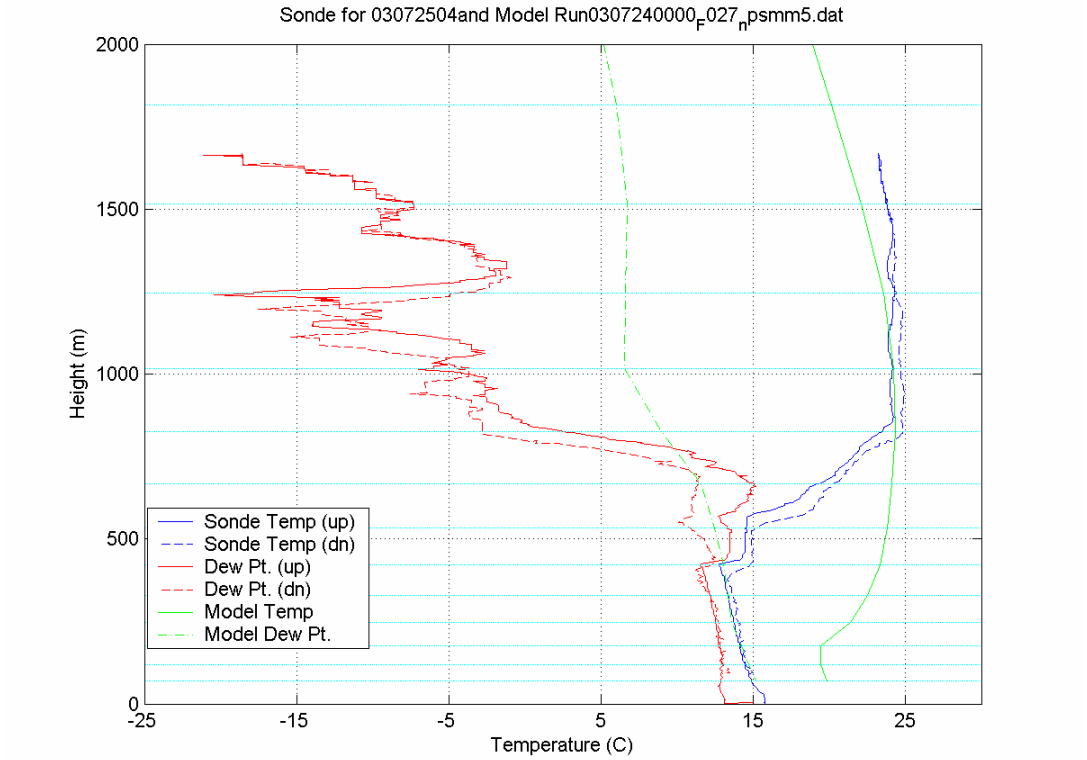
For the analysis, direct comparisons of the temperature, dew point, wind speed and direction were made between each sonde and three correlating model runs to include the two previous forecast and the nearest initilization/analysis . Additionally, a comparison between the three model runs was made to show progression of the forecast. Comments will be provided following each specific event.

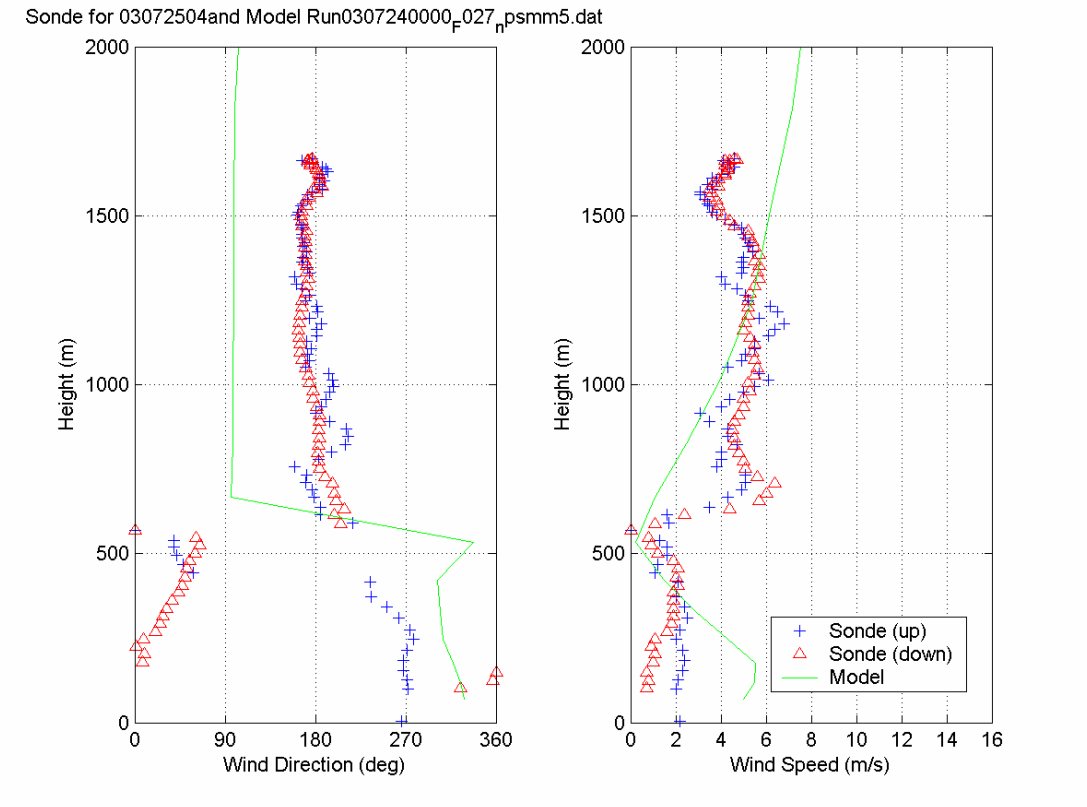
24 July

Synoptically, a week trough with associated low was located over northern California. Conditions when we embarked for the second leg were overcast with light winds at the surface. The synoptic analysis to the left is the NCEP 24 18Z Preliminary Analysis.



Sonde 15


Sonde for 03072504and Model Run0307240000_F027_npsmm5.dat
Height (m)
Temperature (C)
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.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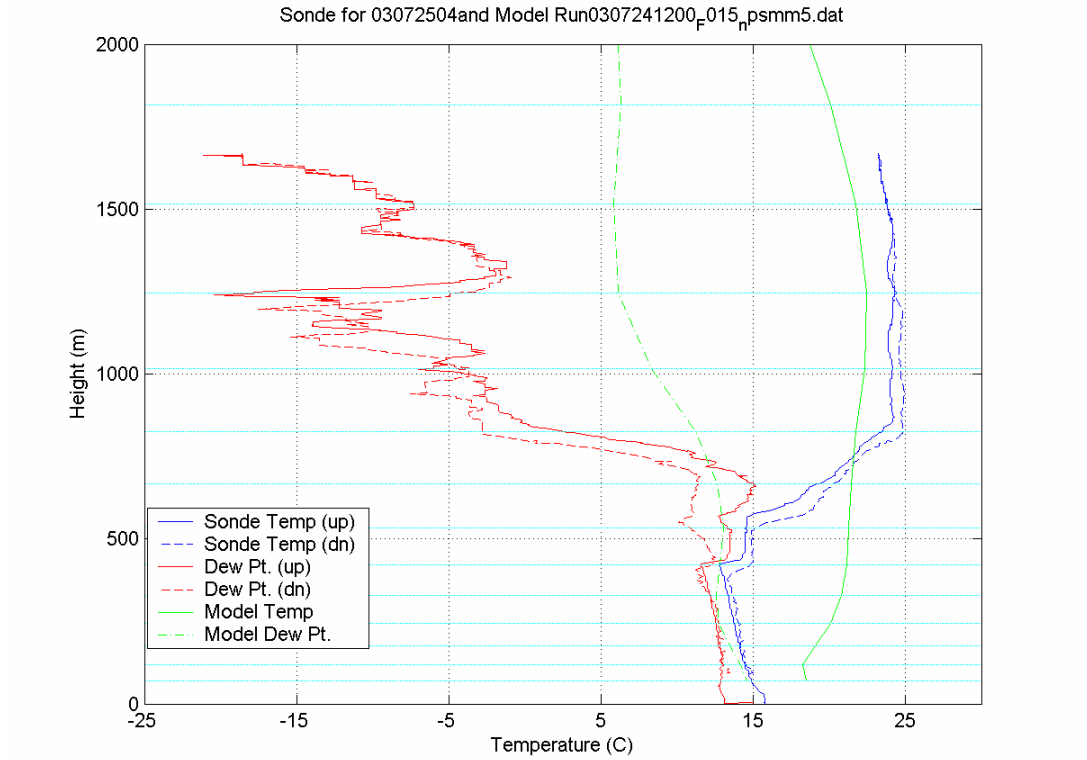
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
Sonde (up)
Sonde (down)
Model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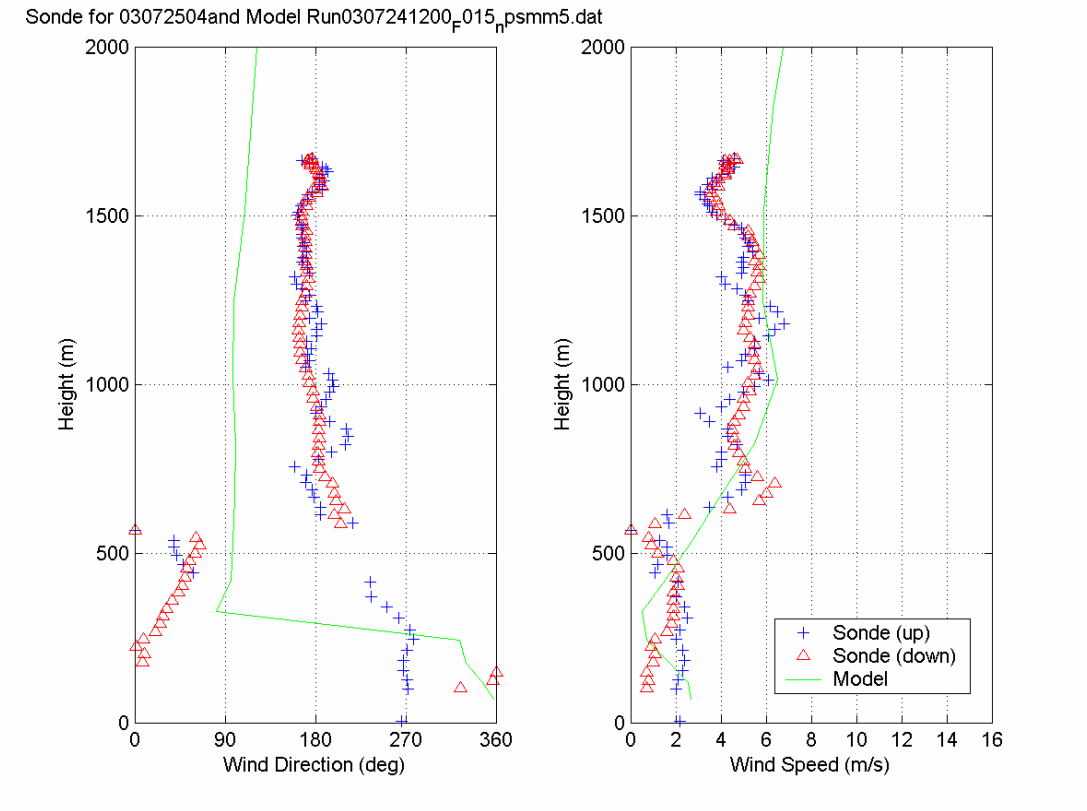
Height (m)
Temperature (C)
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.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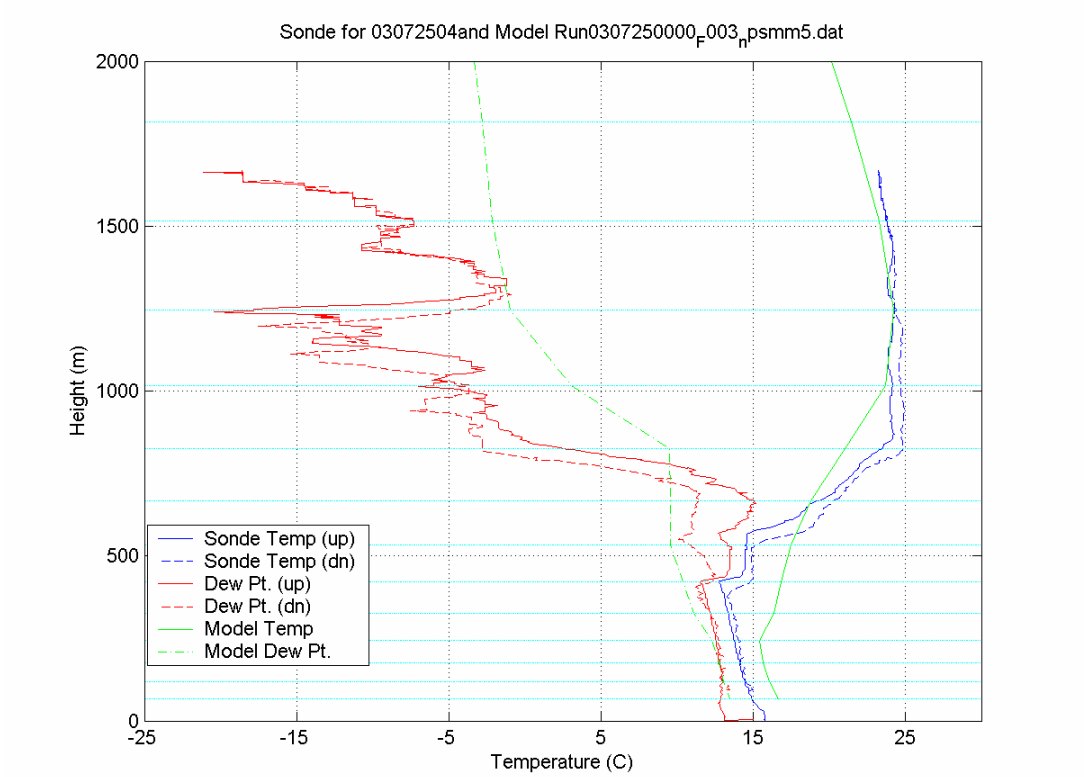
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
Sonde (up)
Sonde (down)
Model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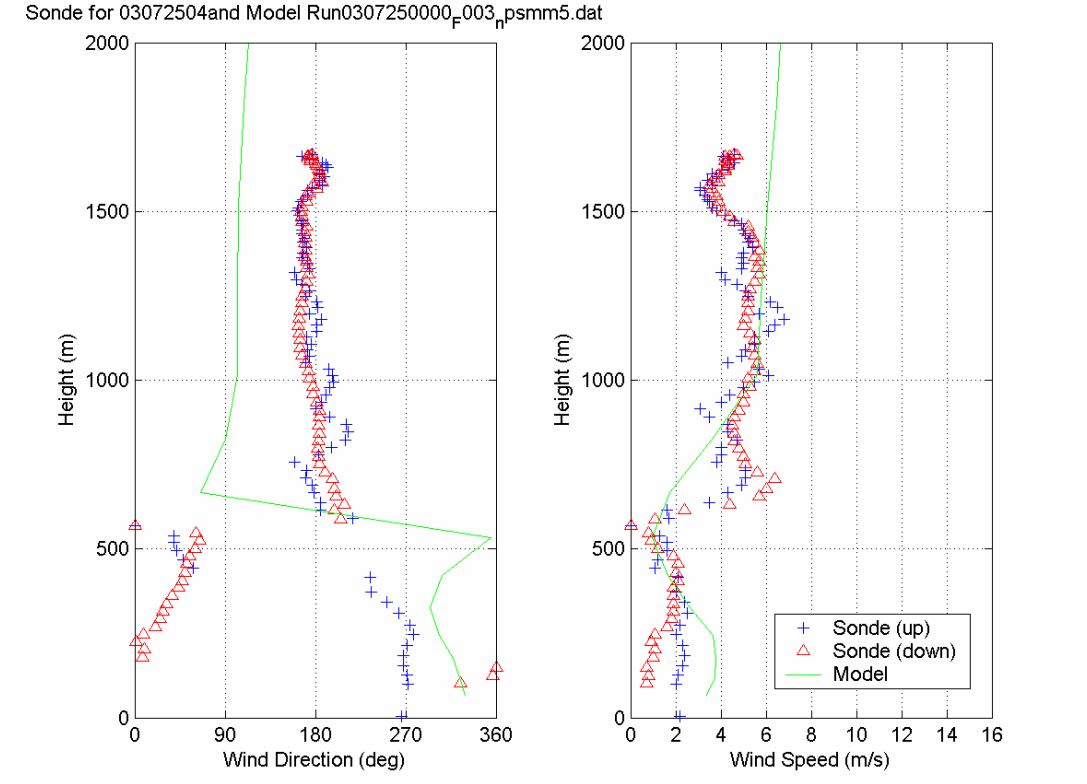
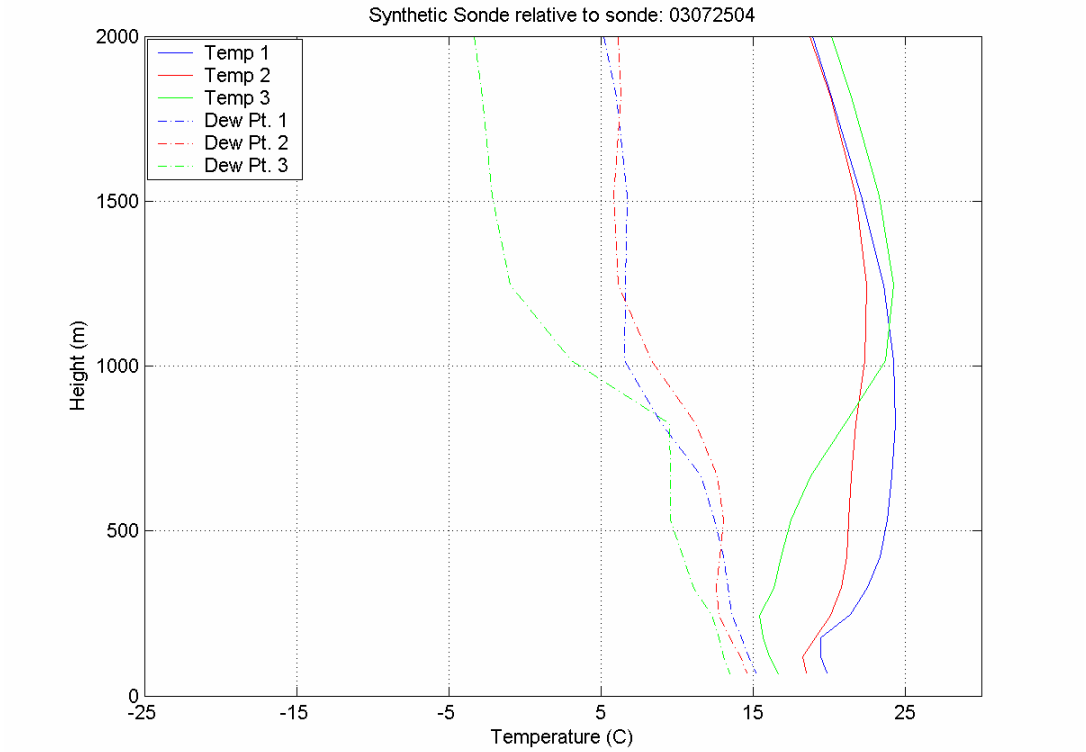
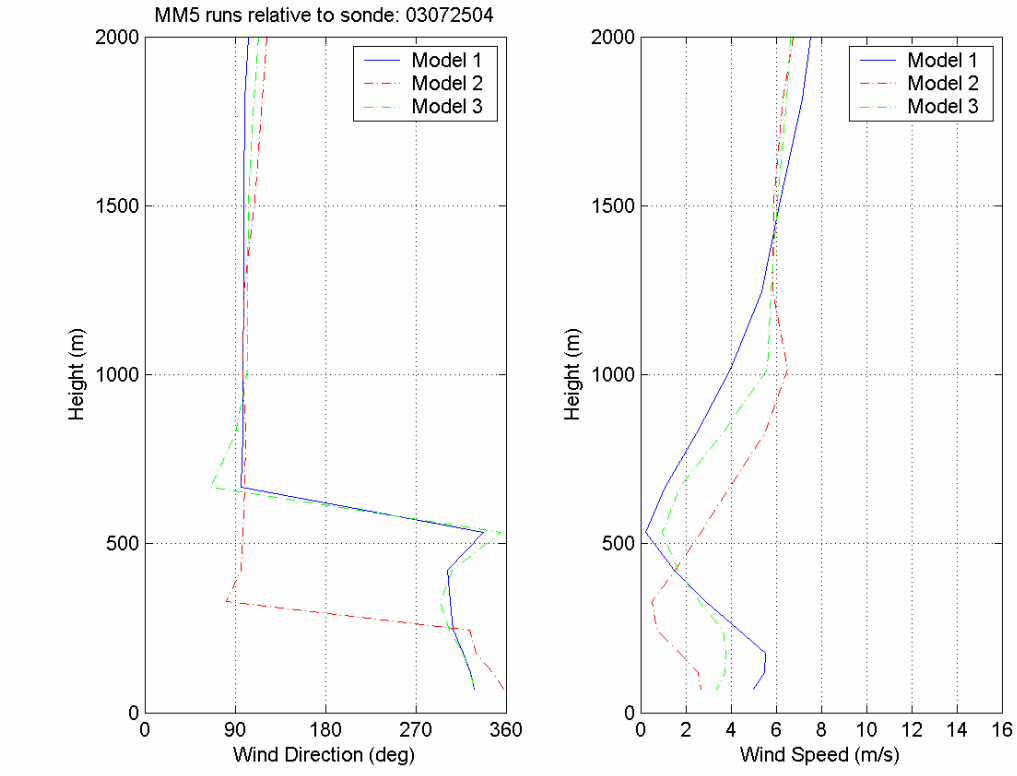
Height (m)
Temperature (C)
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.

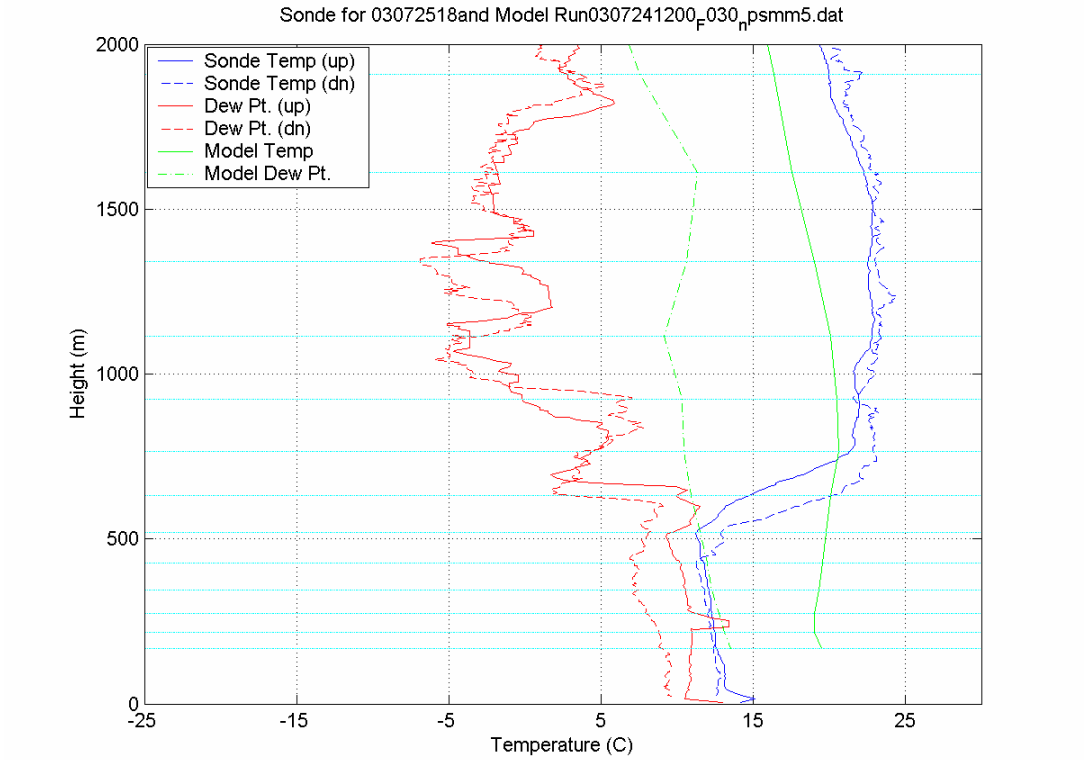

Sonde for 03072504and Model Run0307250000F003npsmm5.dat
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
Sonde (up)
Sonde (down)
Model

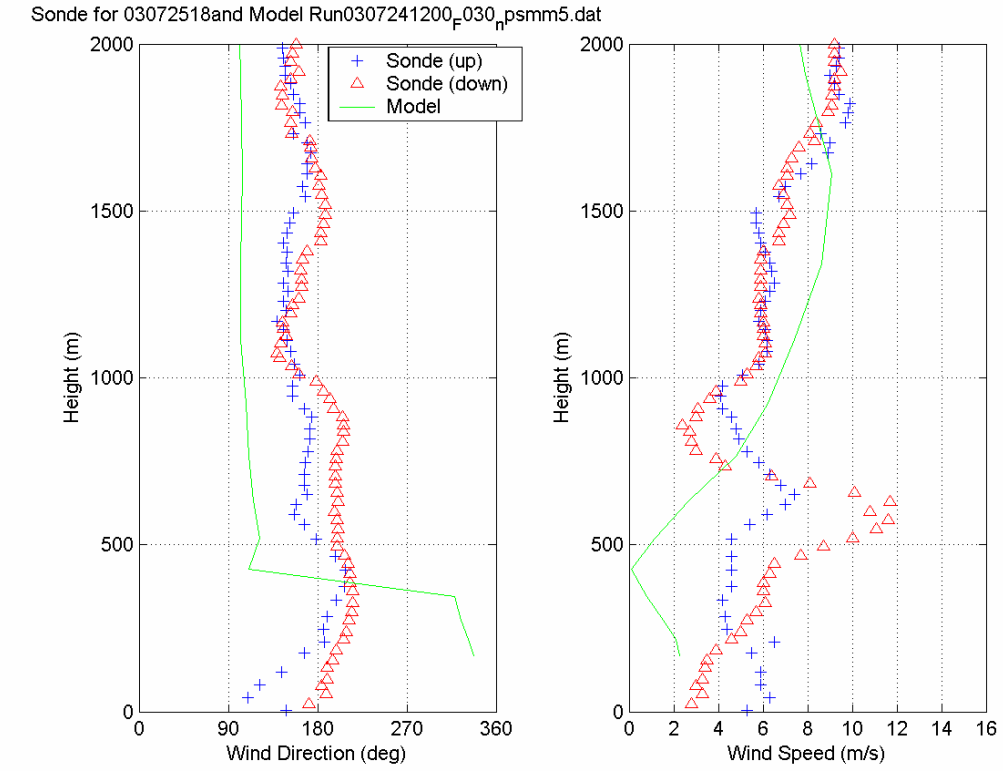
Model Comparison

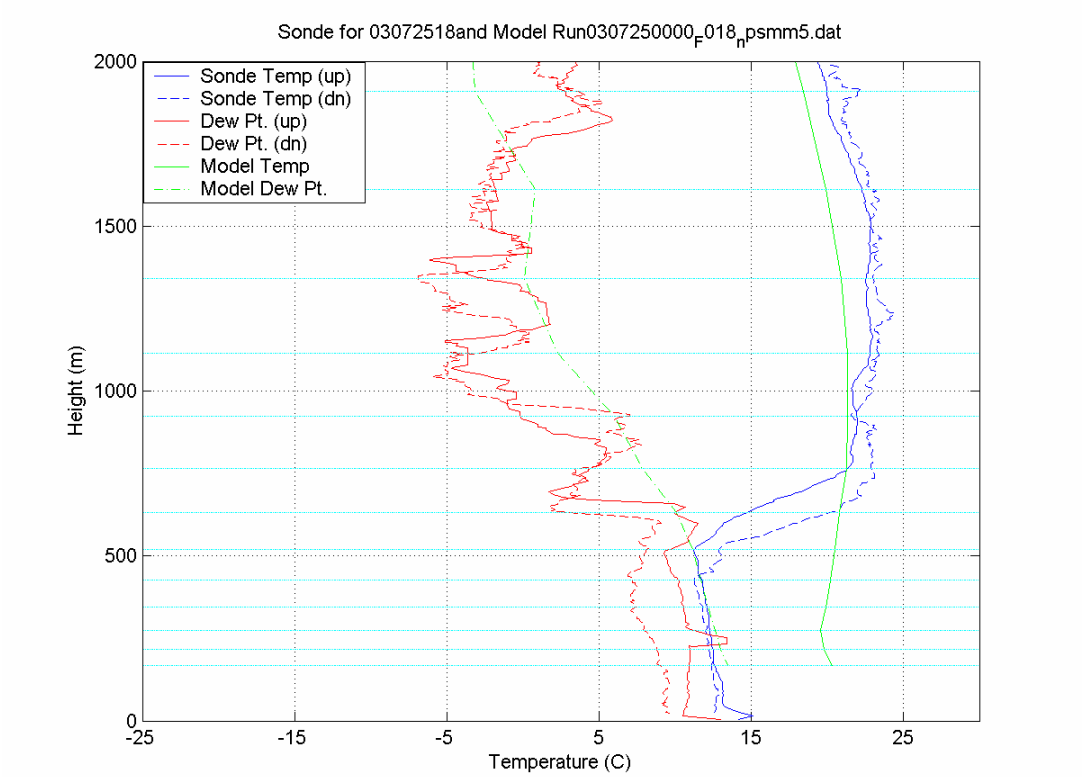




Sonde 16


Sonde for 03072518and Model Run0307241200F030npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072518and Model Run0307241200F030npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)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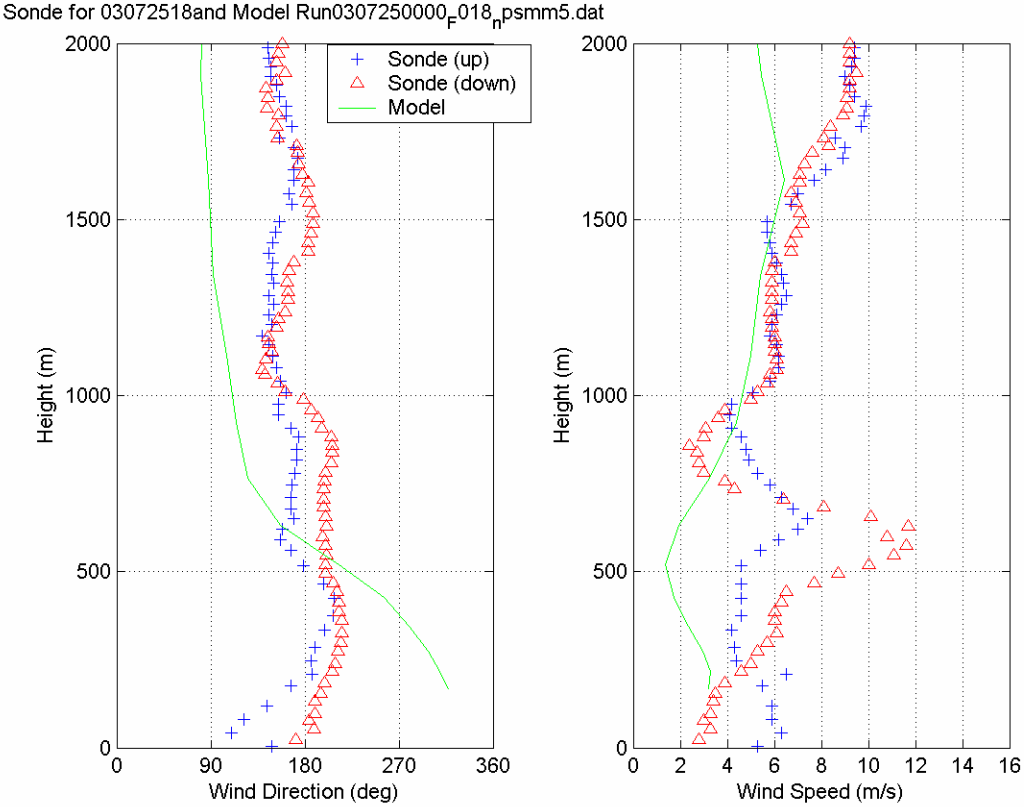
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072518and Model Run0307250000_F018_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
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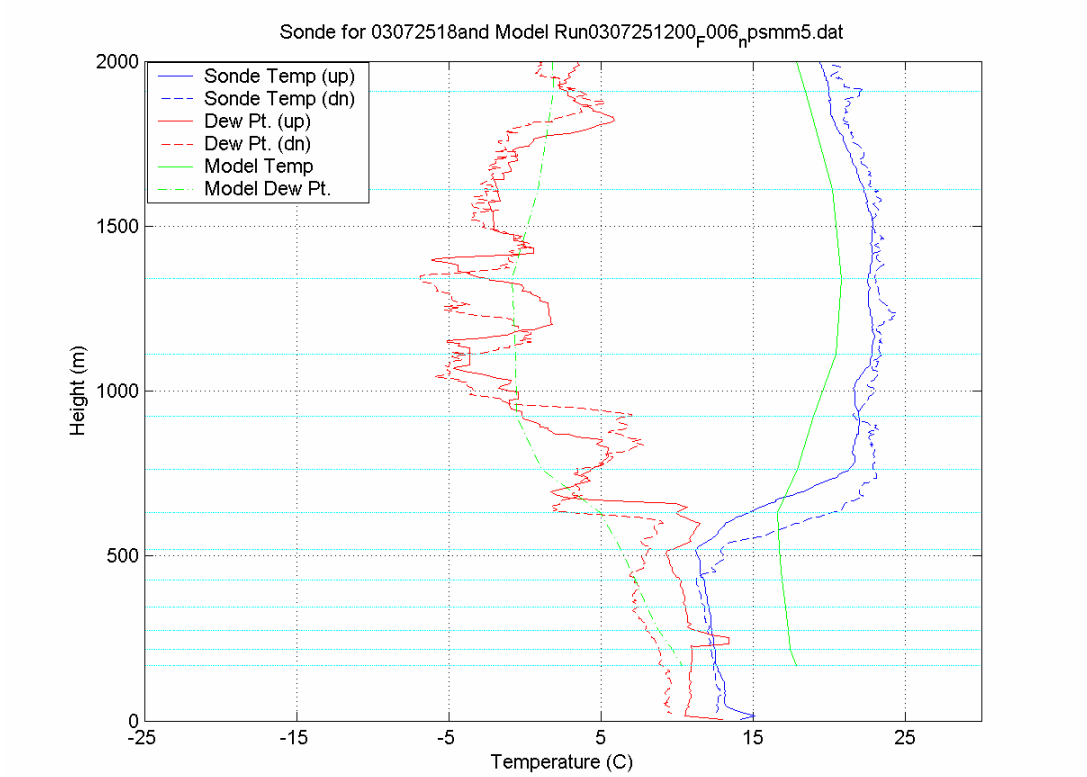
90
180
270
360
2
4
6
8
10
12
14
16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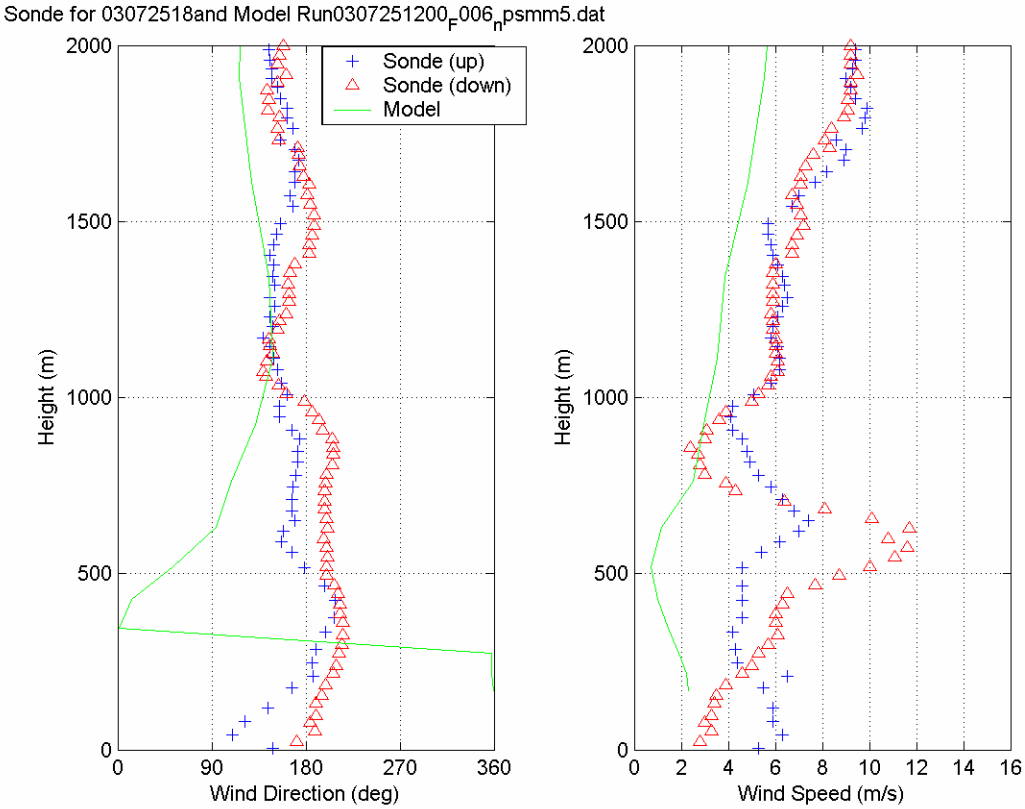
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072518and Model Run0307251200_F006_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
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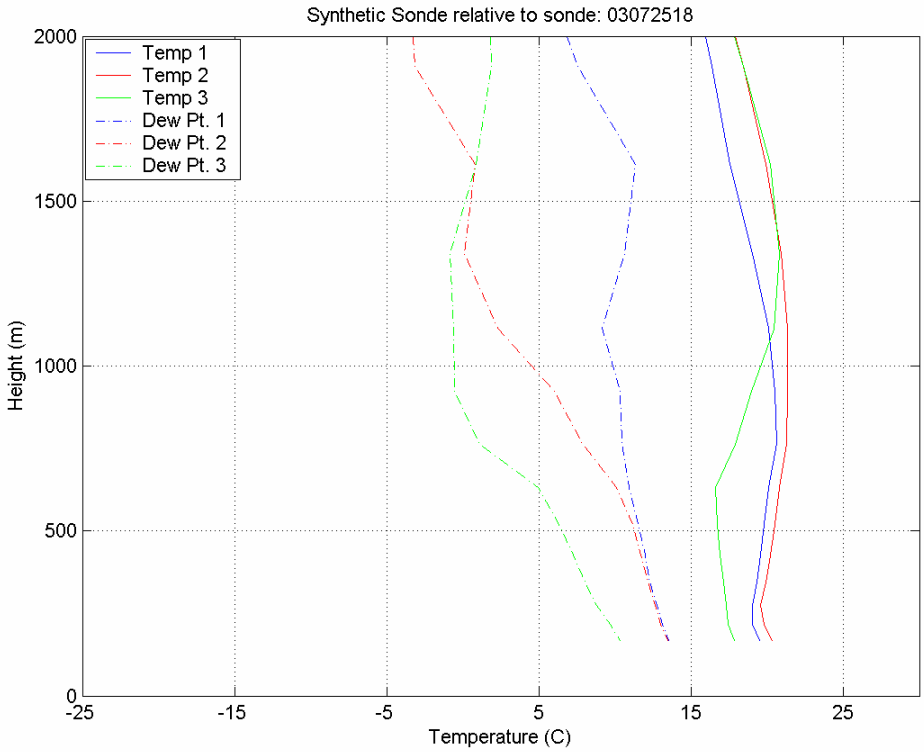
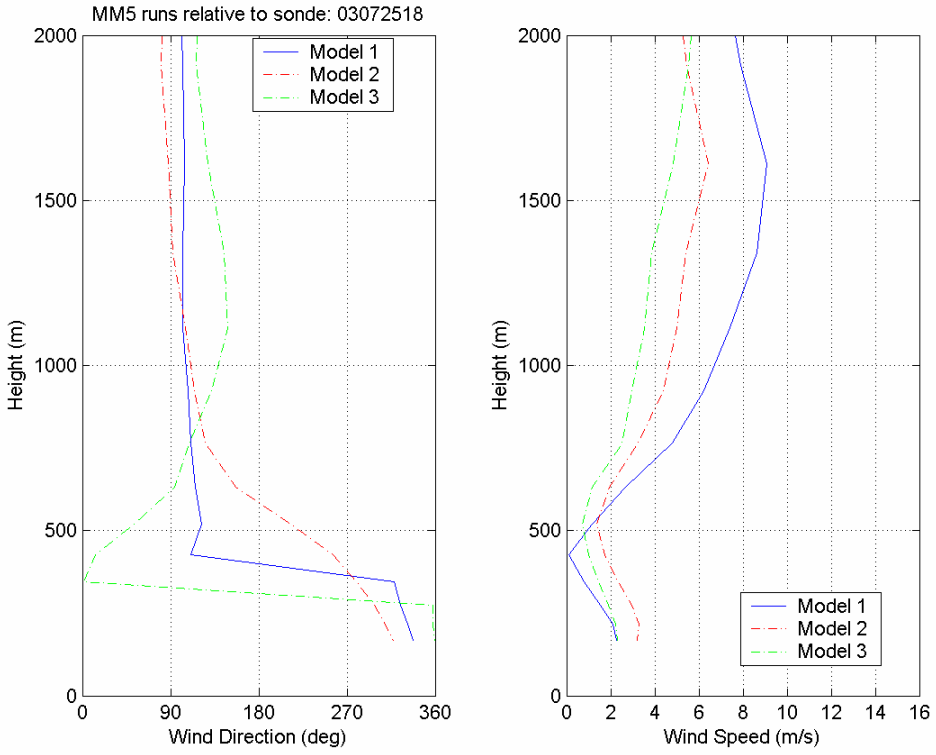
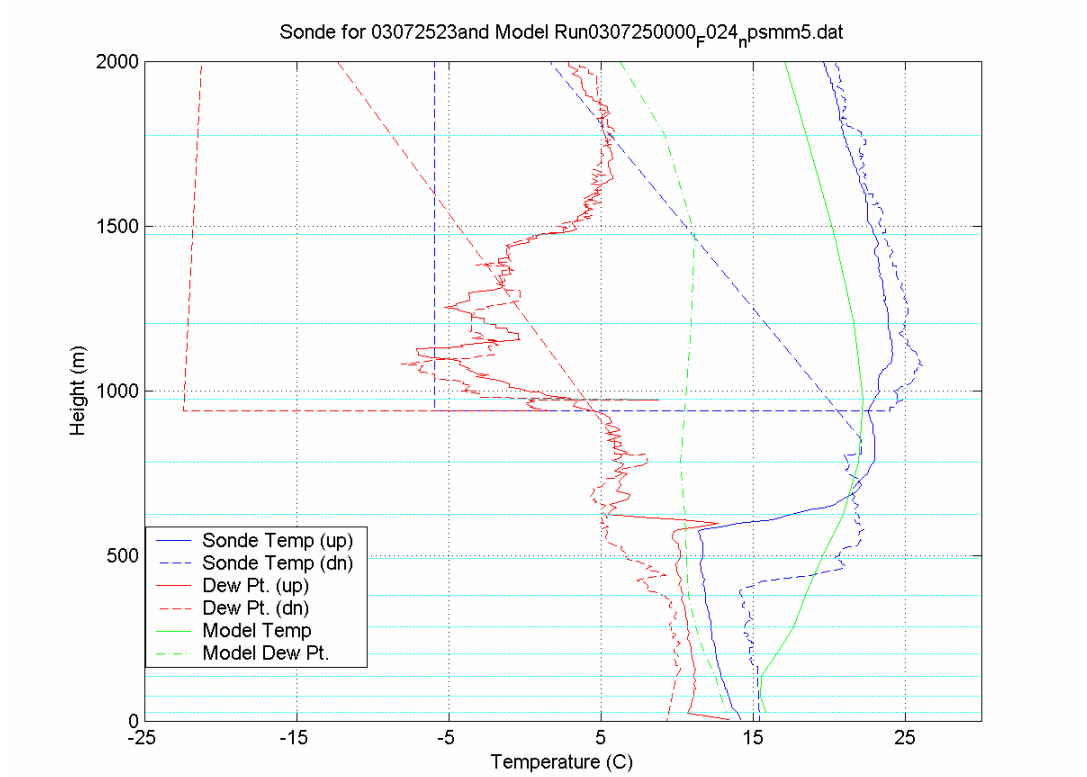
12
14
16

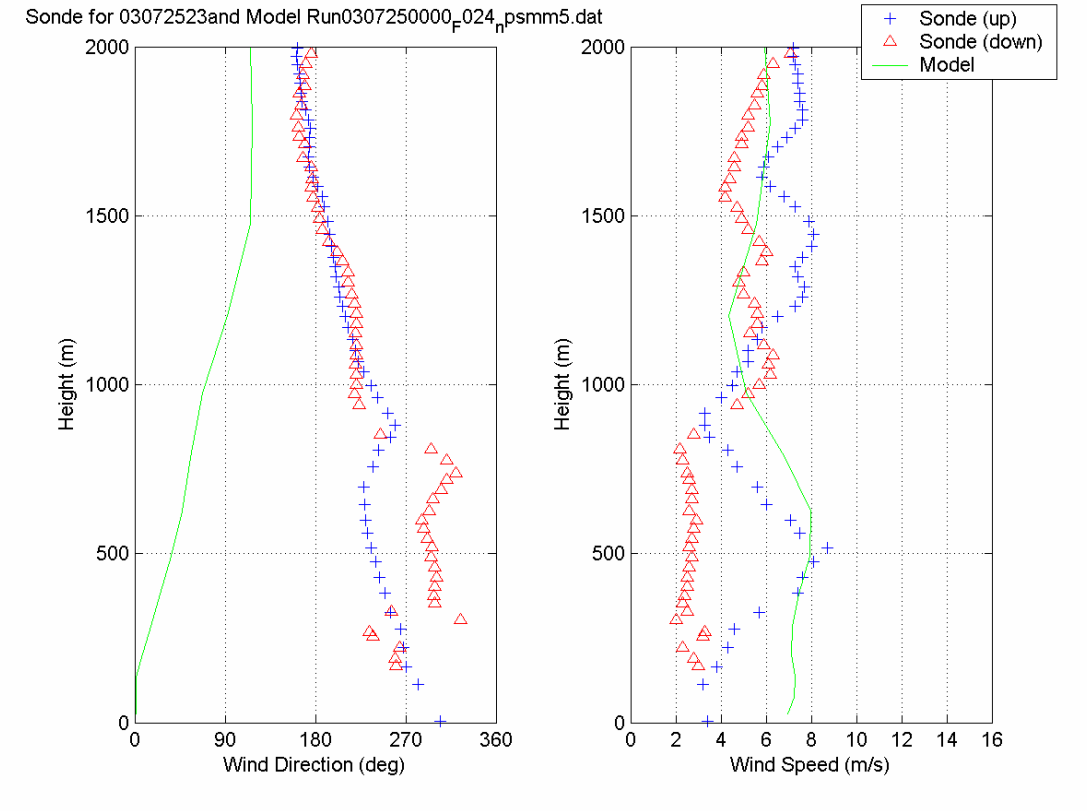
Model Comparison

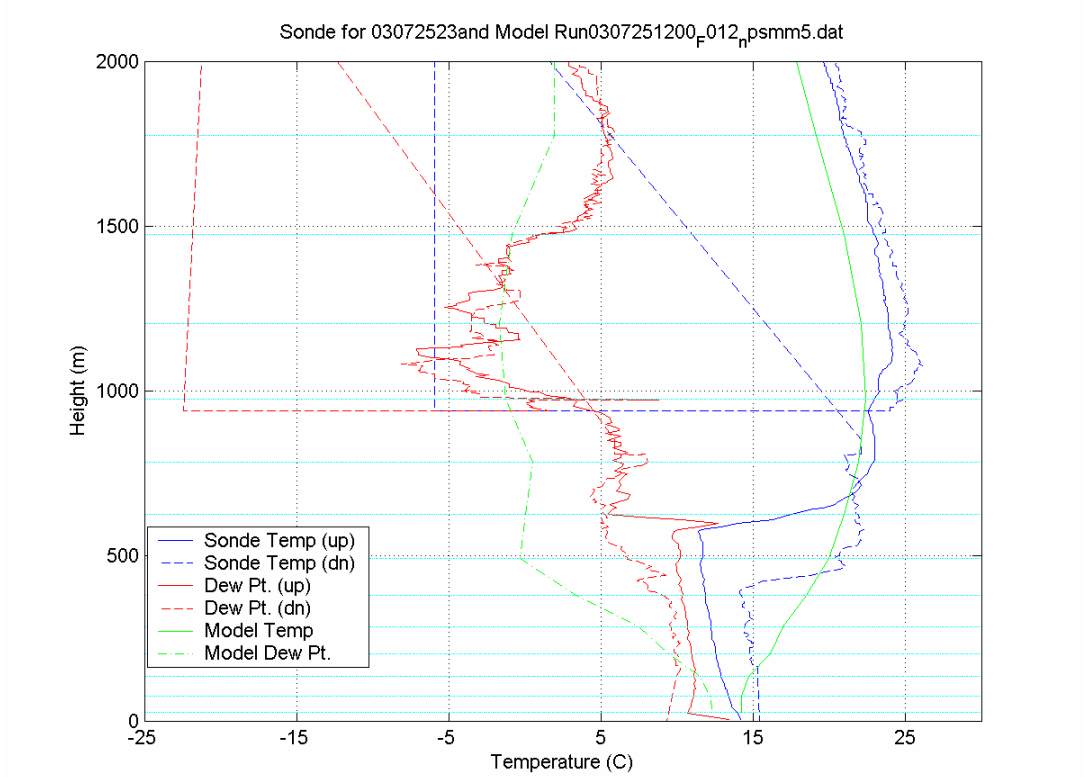




Sonde 17


Sonde for 03072523and Model Run0307250000_F024_npsmm5.dat
Height (m)
Temperature (C)
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.


Sonde for 03072523and Model Run0307250000_F024_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)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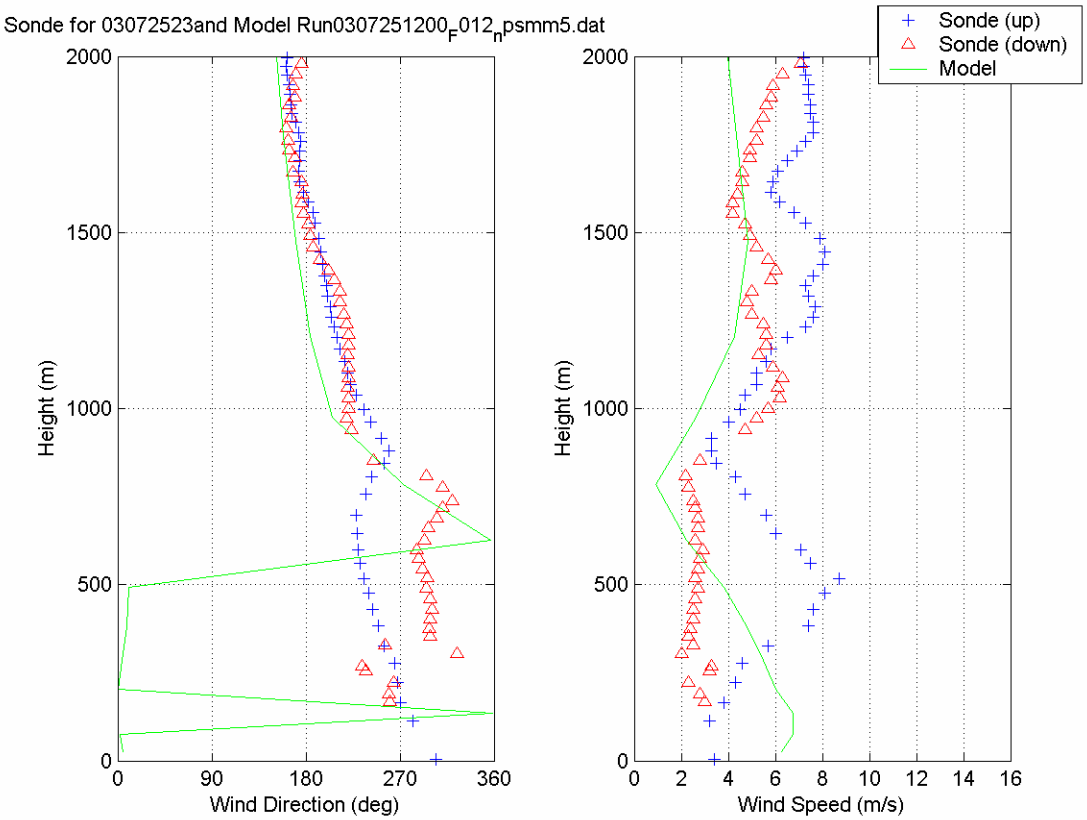
Height (m)
Temperature (C)
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.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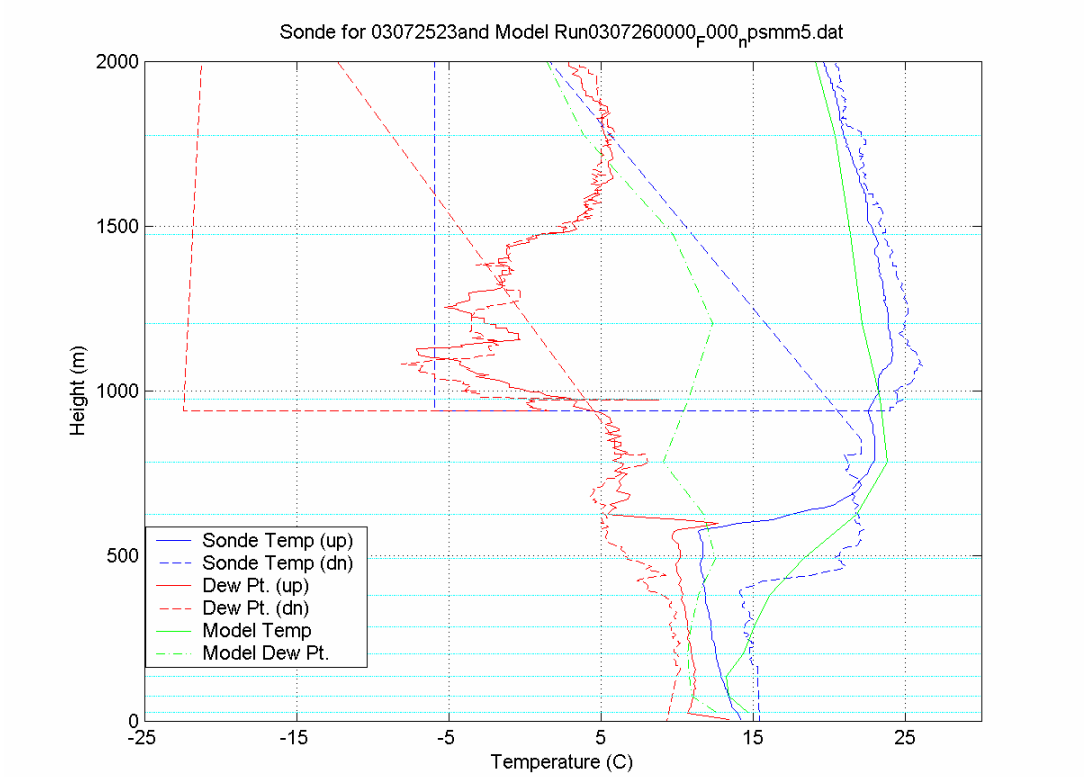
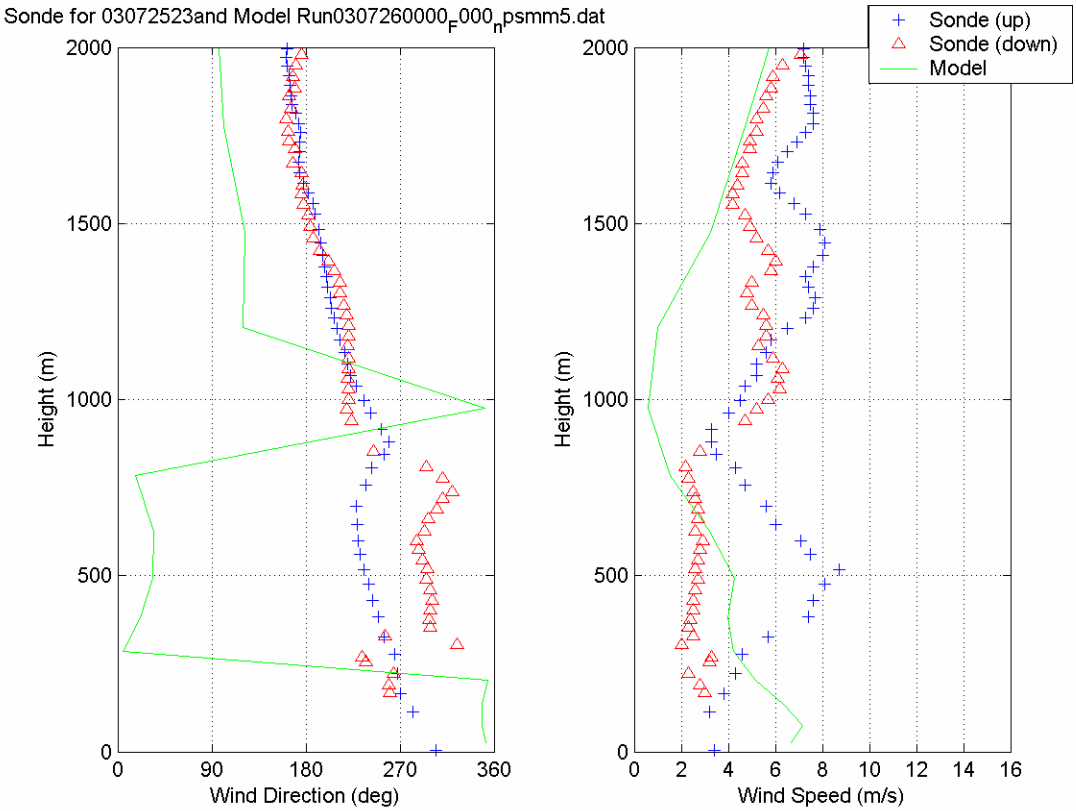
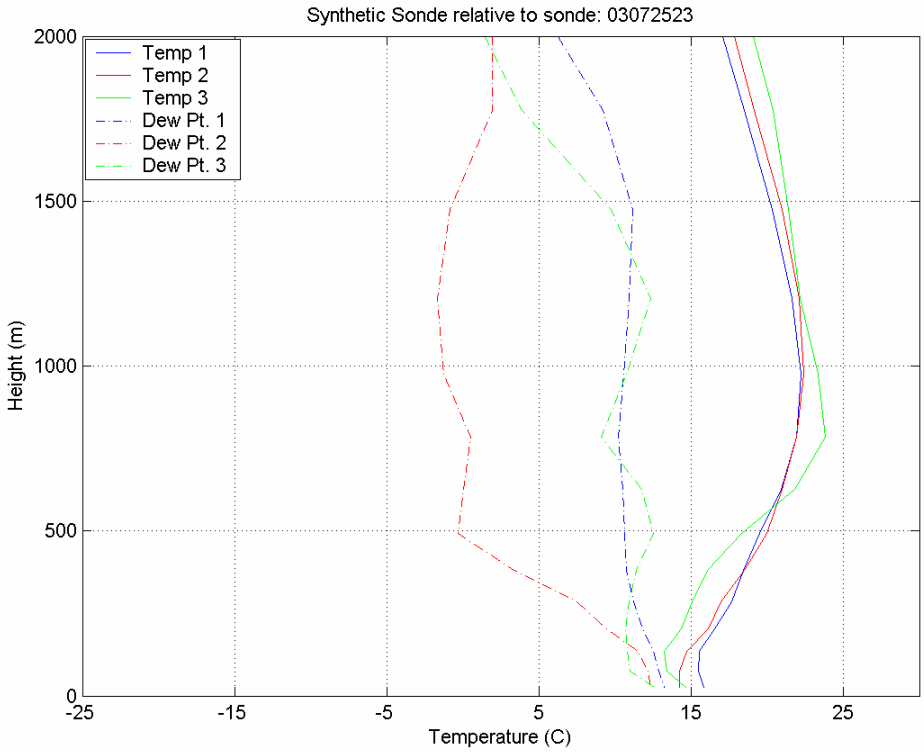
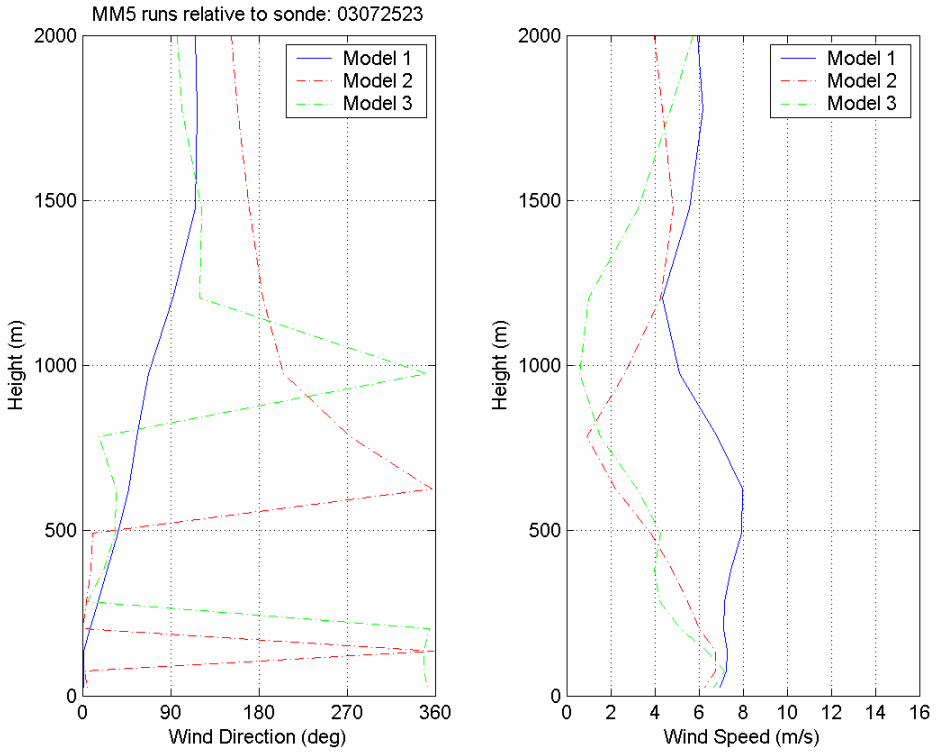
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)


Sonde for 03072523and Model Run0307260000F000npsmm5.dat
Height (m)
Temperature (C)
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.

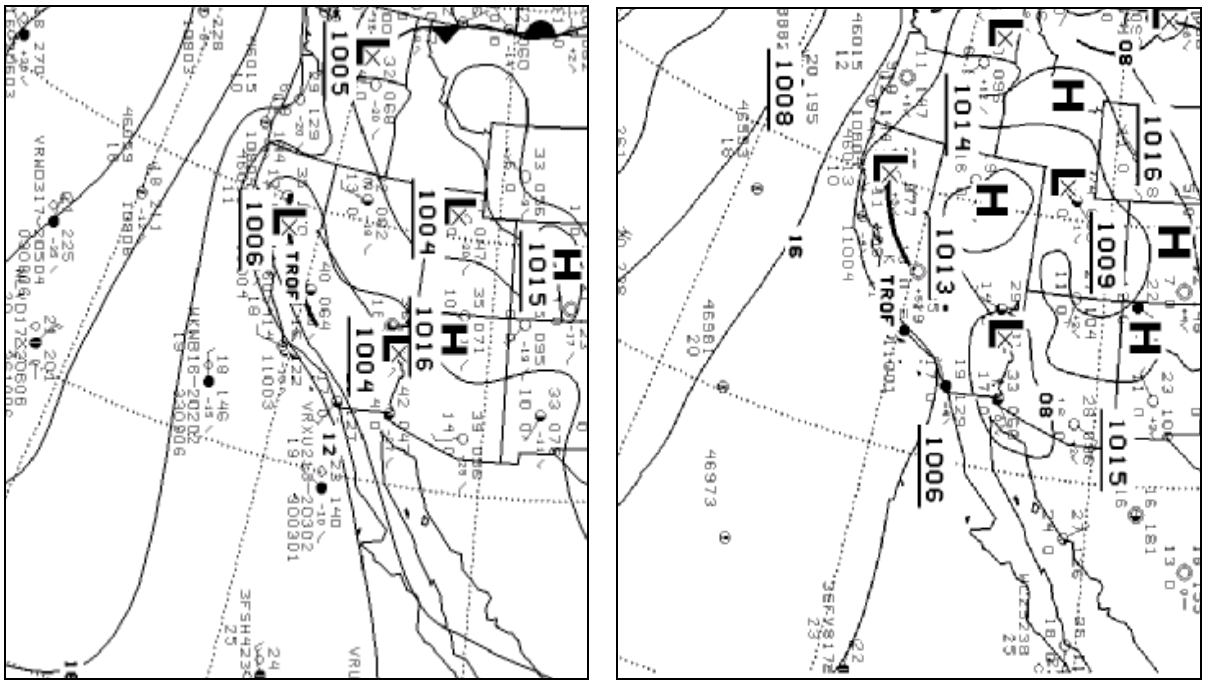

Sonde for 03072523and Model Run0307260000F000npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)

Model Comparison





Synoptic Situation on 25 July



NCEP 00Z and 12Z Preliminary Analysis. Stationary low located over Northern California with associated trough (leeside induced) extending to the south. High pressure building slightly to the west later in period.

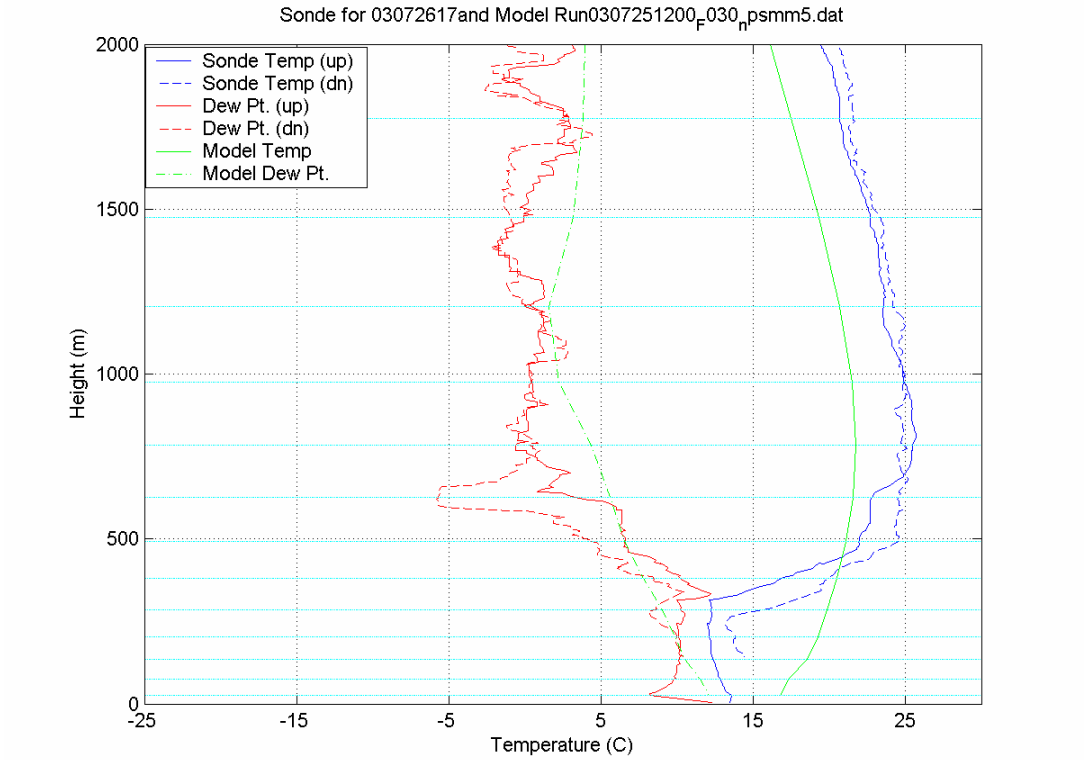
Notes

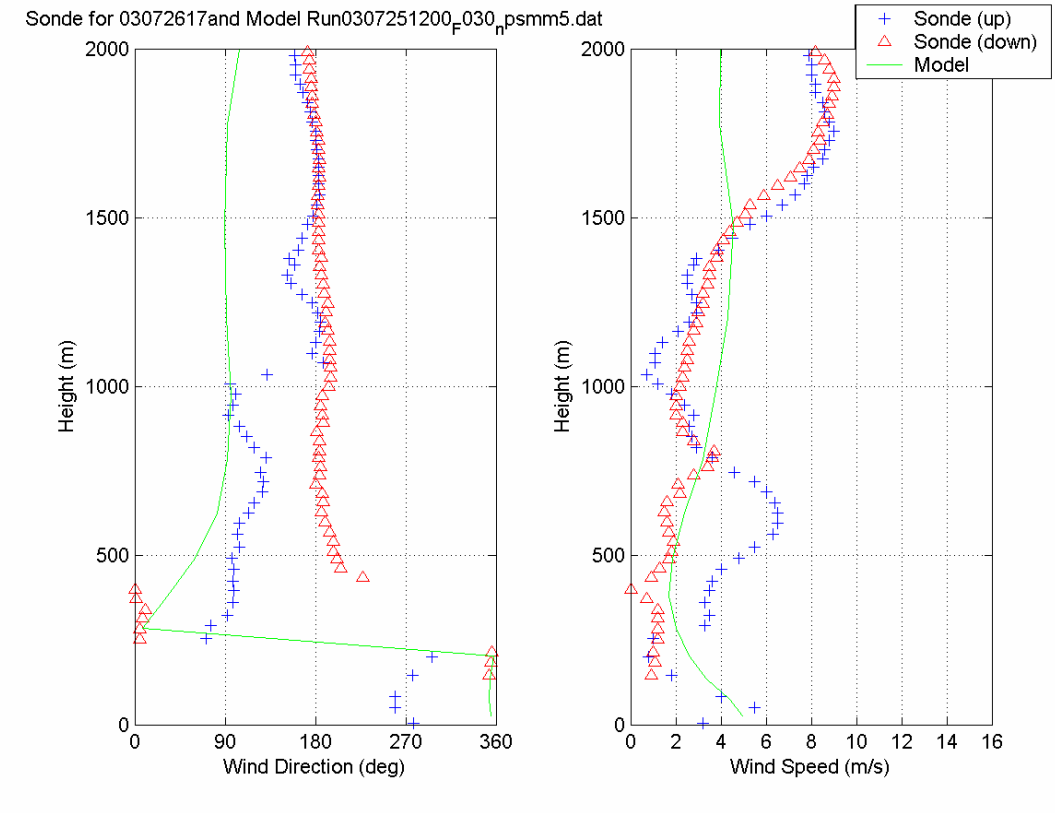
Sonde 15: Appears to have a good profile for comparison. F27 and F15 both depict inversion level much lower than the observed level by approximately 500m or more. Wind directions are consistently about 90□out, usually depicting Easterlies when southerly winds prevail. Wind speeds actually show trend well, especially above 500m, but tend to be excessive below 500m. F03 much improved profile as would be expected. Comparison of models show improvement over 27 period.

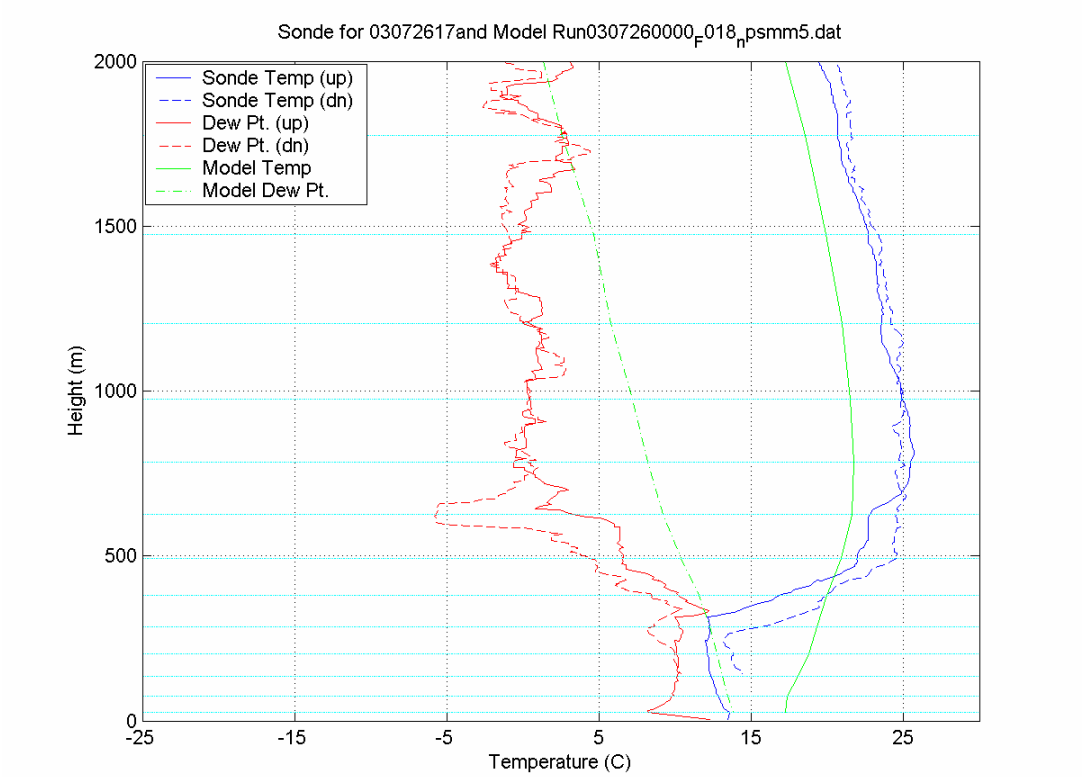
Sonde 16: Good sonde profile but all forecast are suspect at this point. Lower level of model starts at approximately 200m above the surface. This indicates that the nearest grid point is actually over land, possibly the inter-coastal mountain range. Good representation of draw backs encountered with a 12 km grid and complex terrain.

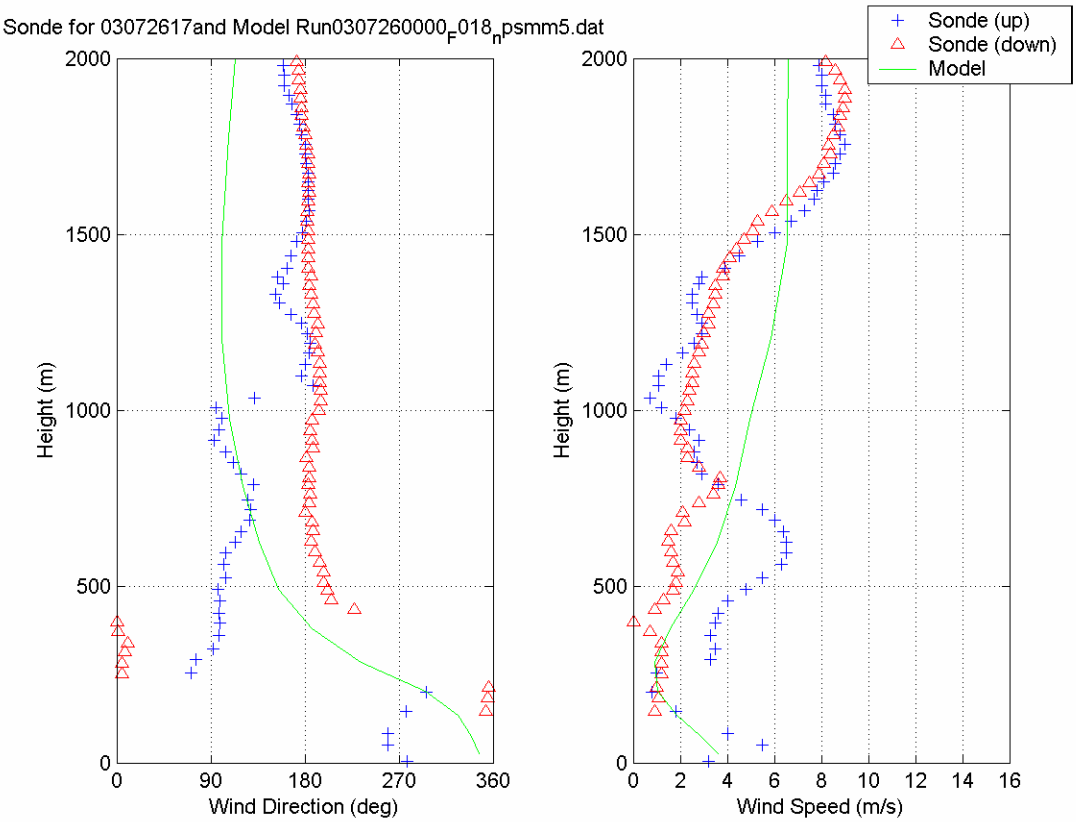
Sonde 17: Sonde has some bad data points but still holds useful data. F24 and F12 depict inversion lower than actual but F12 clearly shows better definition. F00 height is correct but moisture aloft is greater than actual. F24 wind direction are bad at lower heights then get worse before finally getting better. F12 tracks wind direction well. Wind speeds in all cases were over estimated below 500m but improve above.

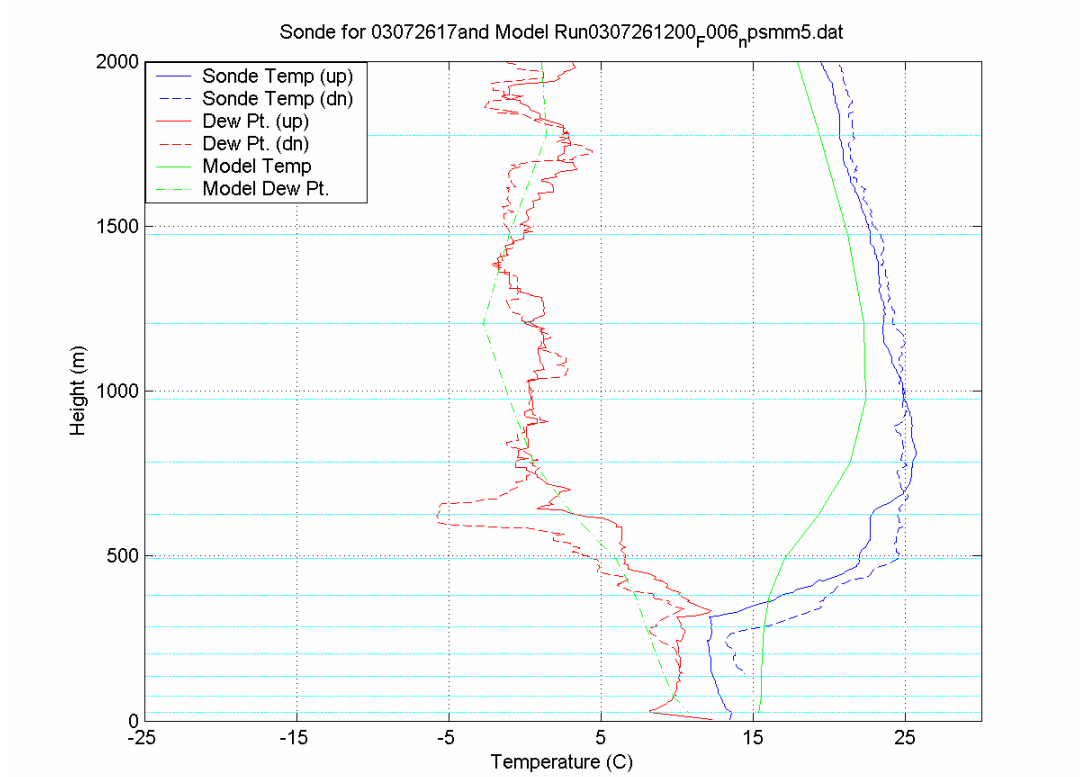
Sonde 18


Sonde for 03072617and Model Run0307251200F030npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072617and Model Run0307251200F030npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)


Sonde for 03072617and Model Run0307260000_F018_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072617and Model Run0307260000_F018_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)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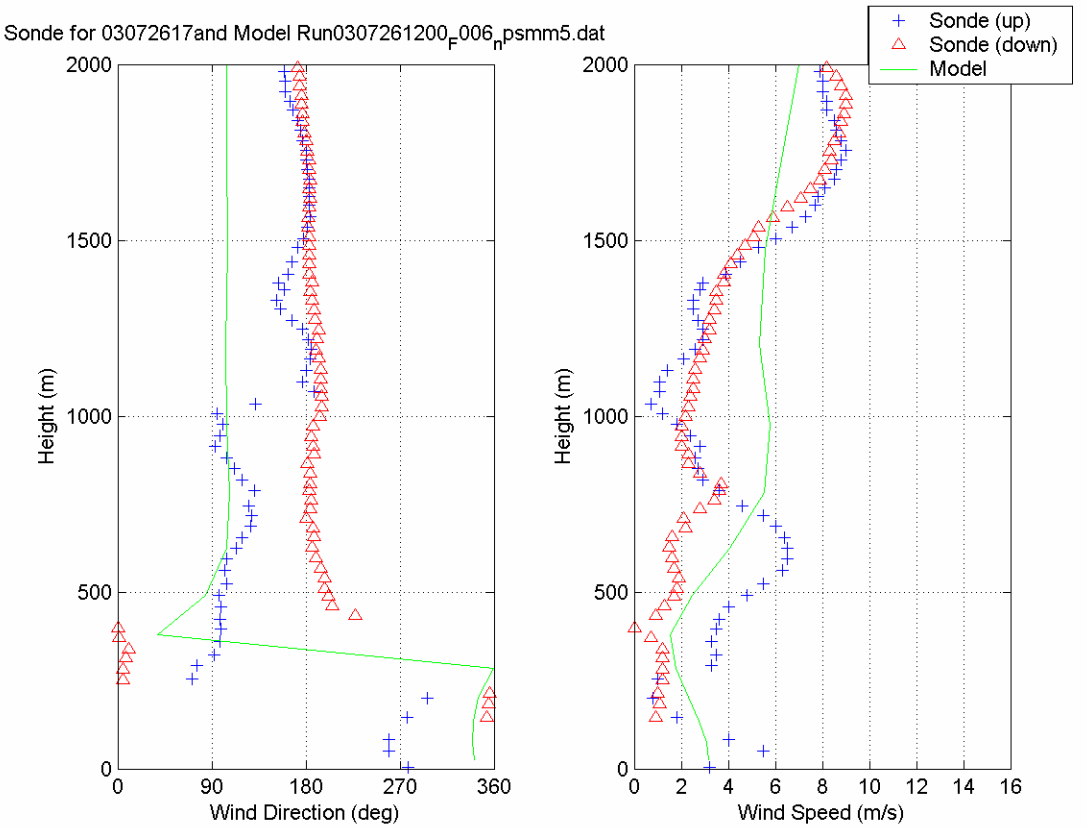
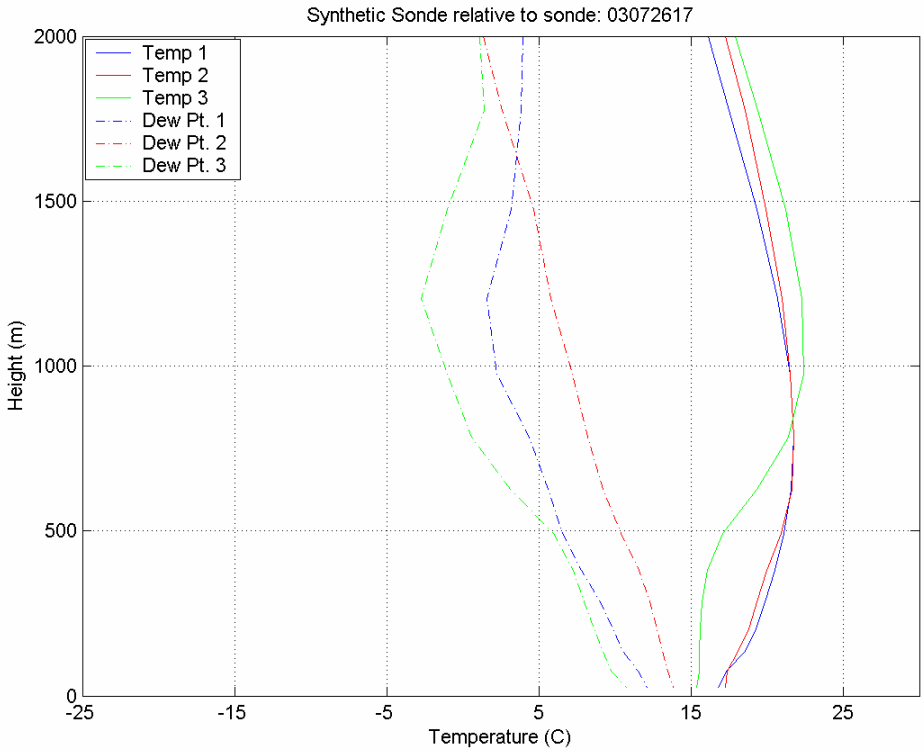
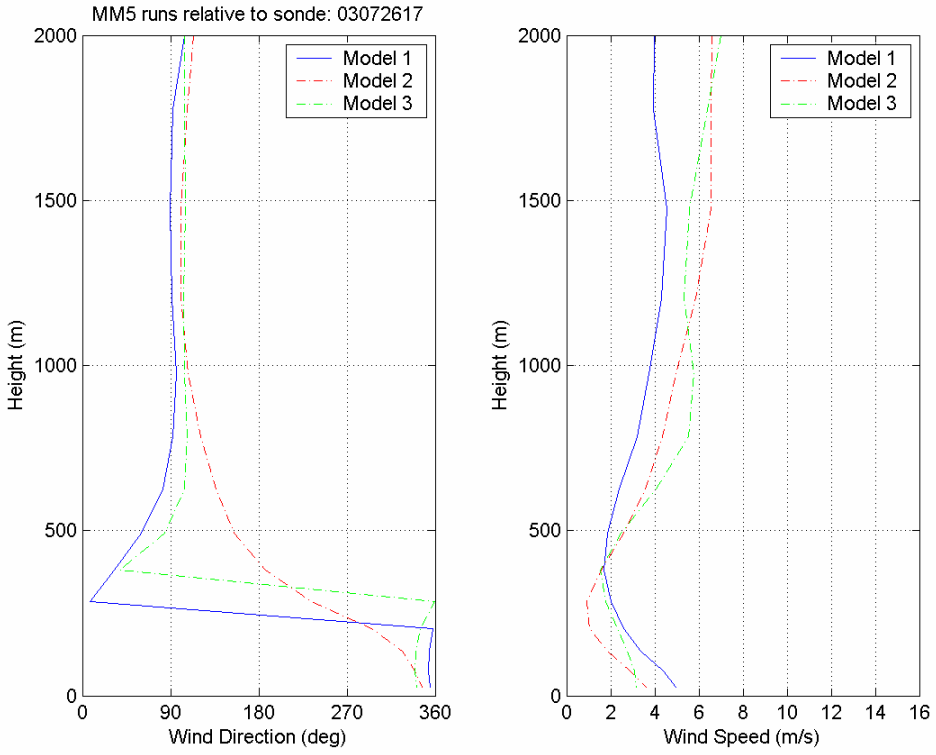
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)

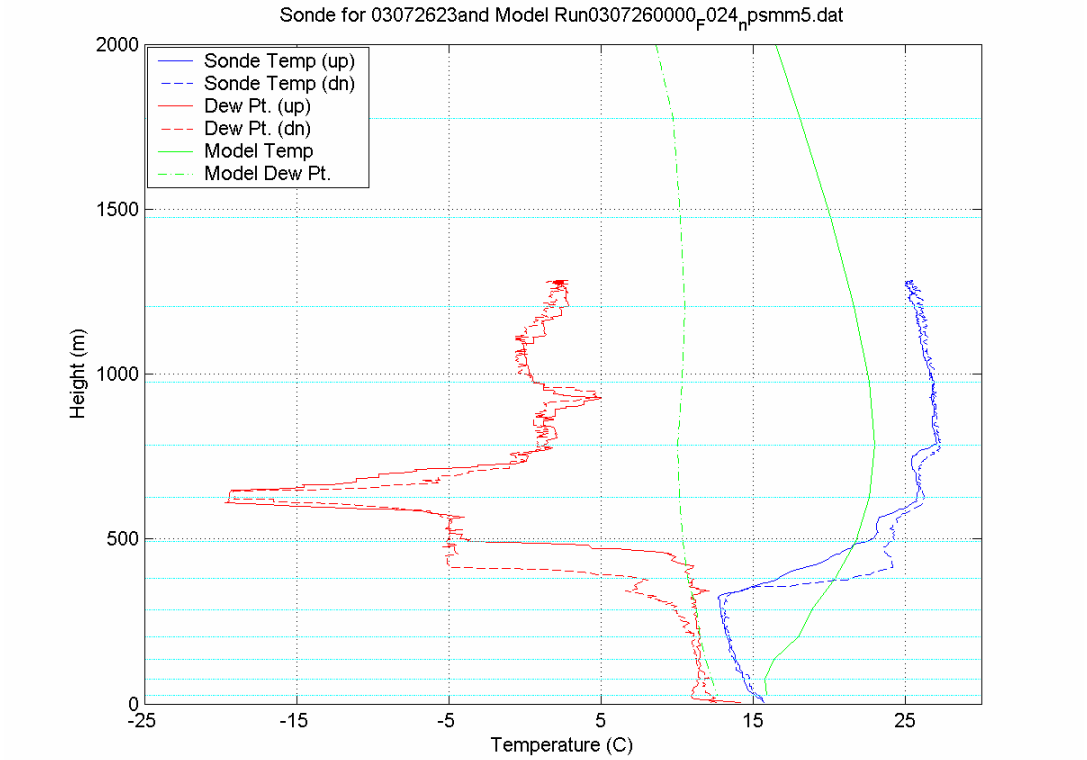

Sonde for 03072617and Model Run0307261200F006npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)

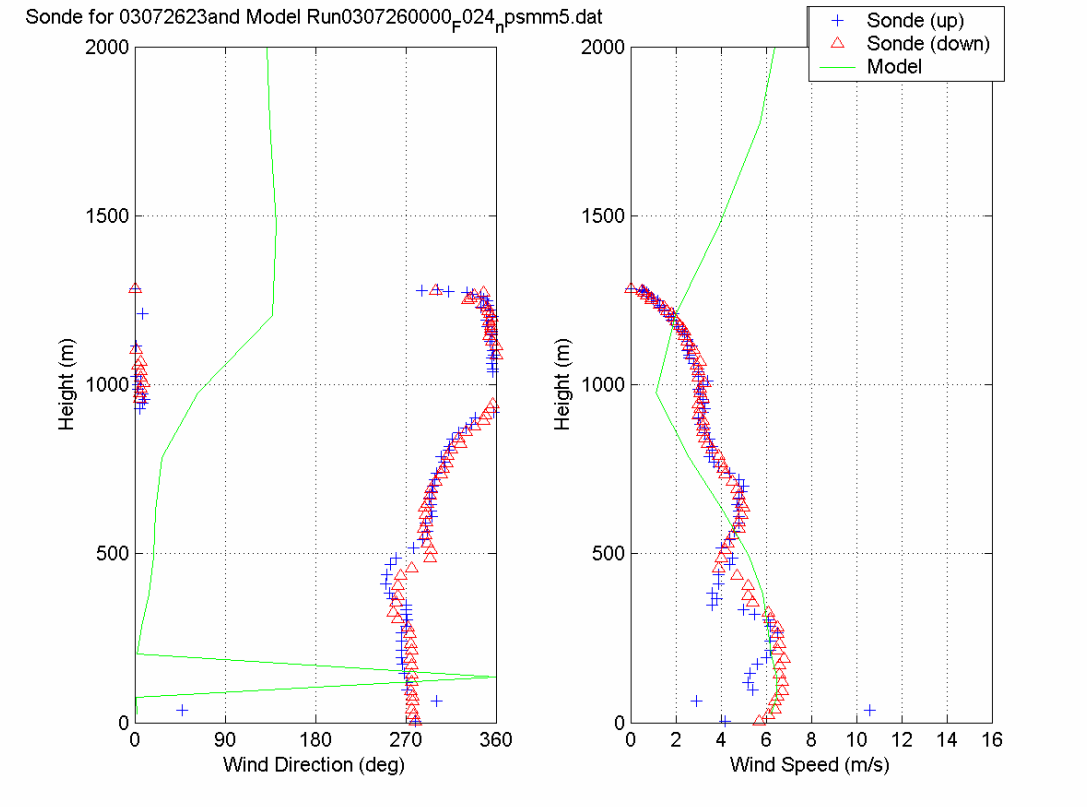
Model Comparison

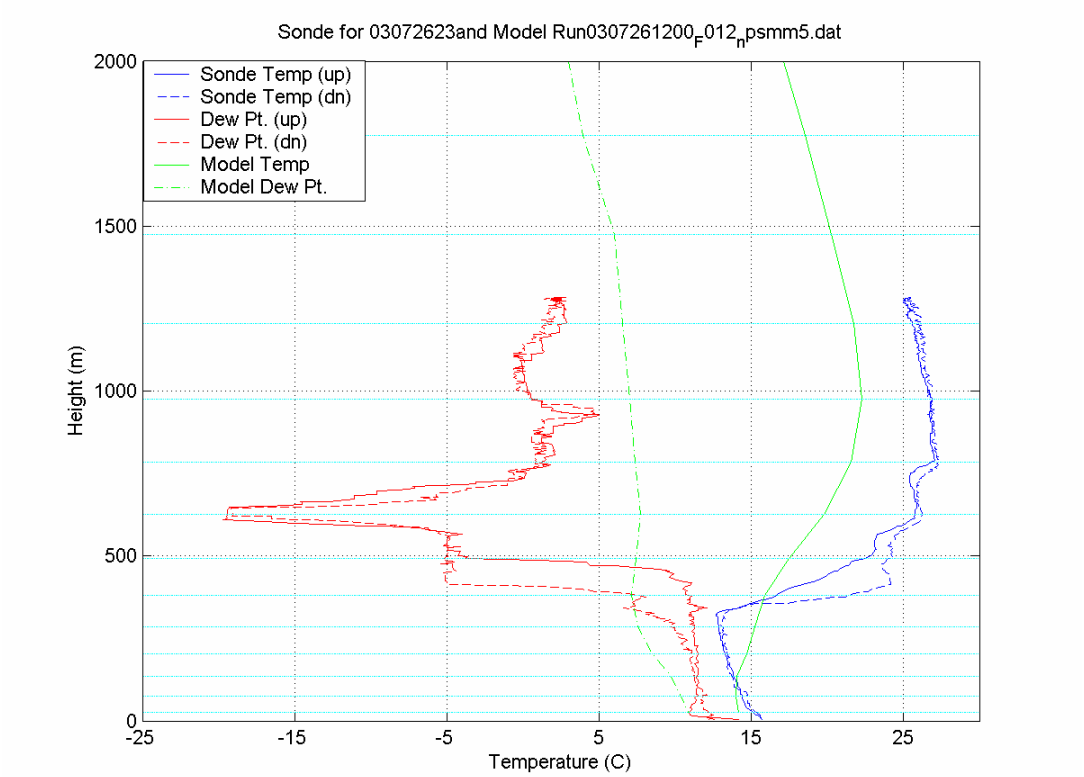


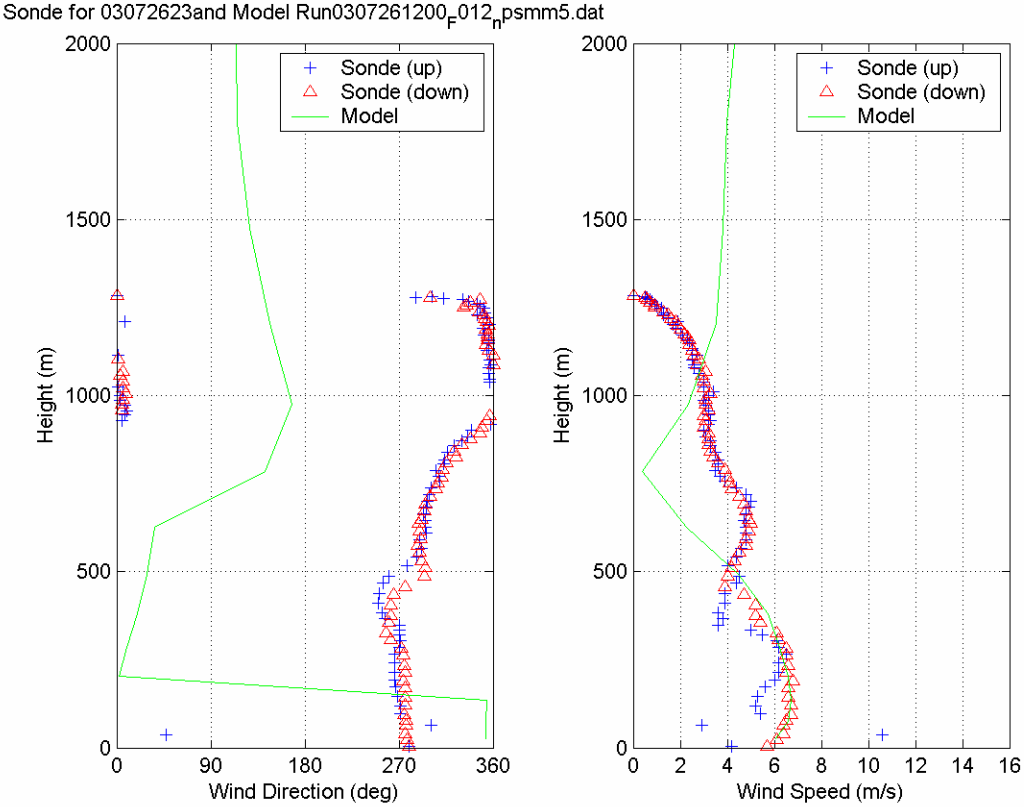


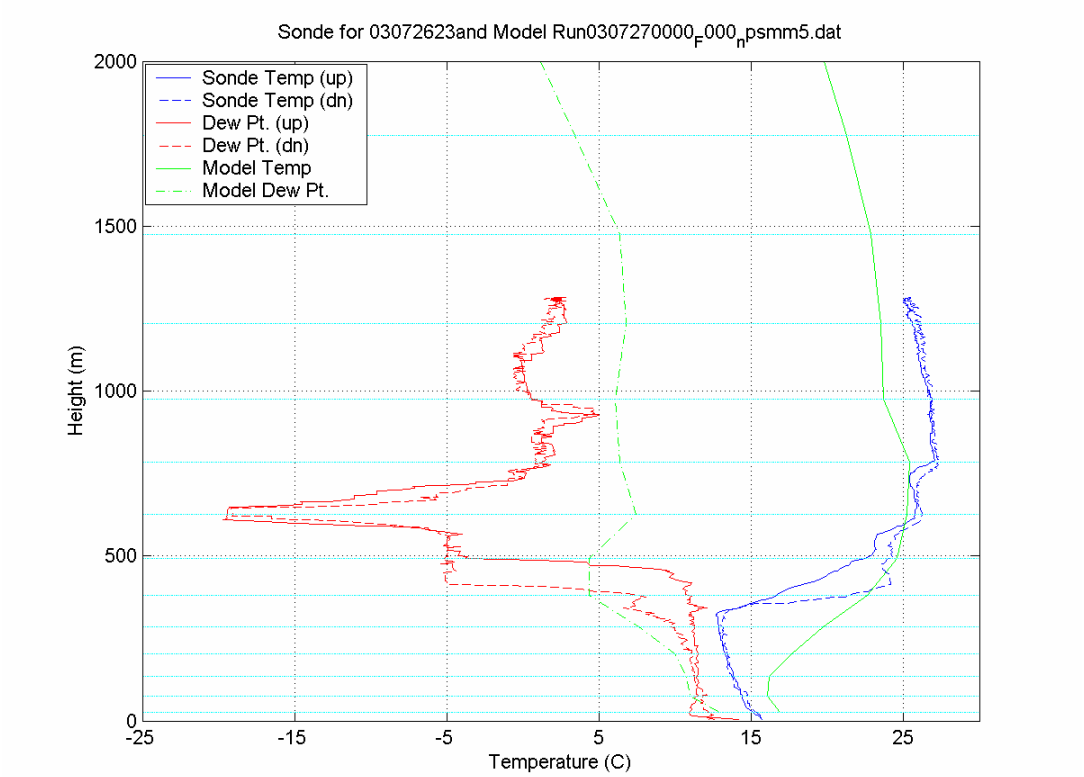
Sonde 19

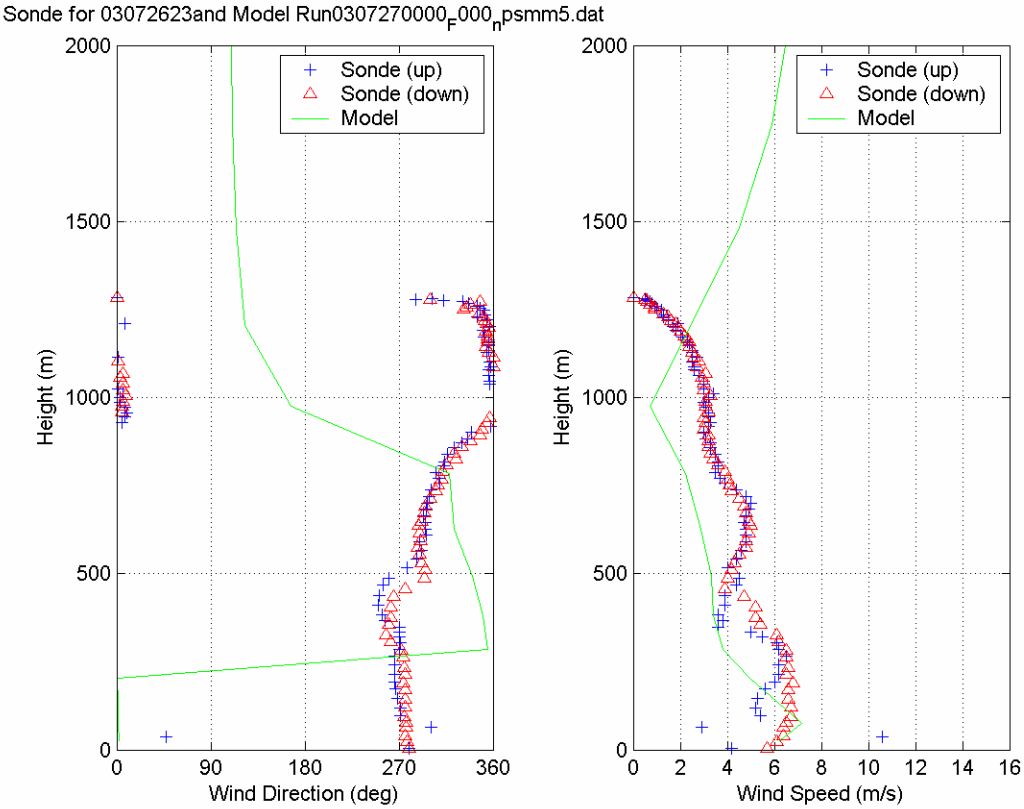

Sonde for 03072623and Model Run0307260000_F024_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072623and Model Run0307260000_F024_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)

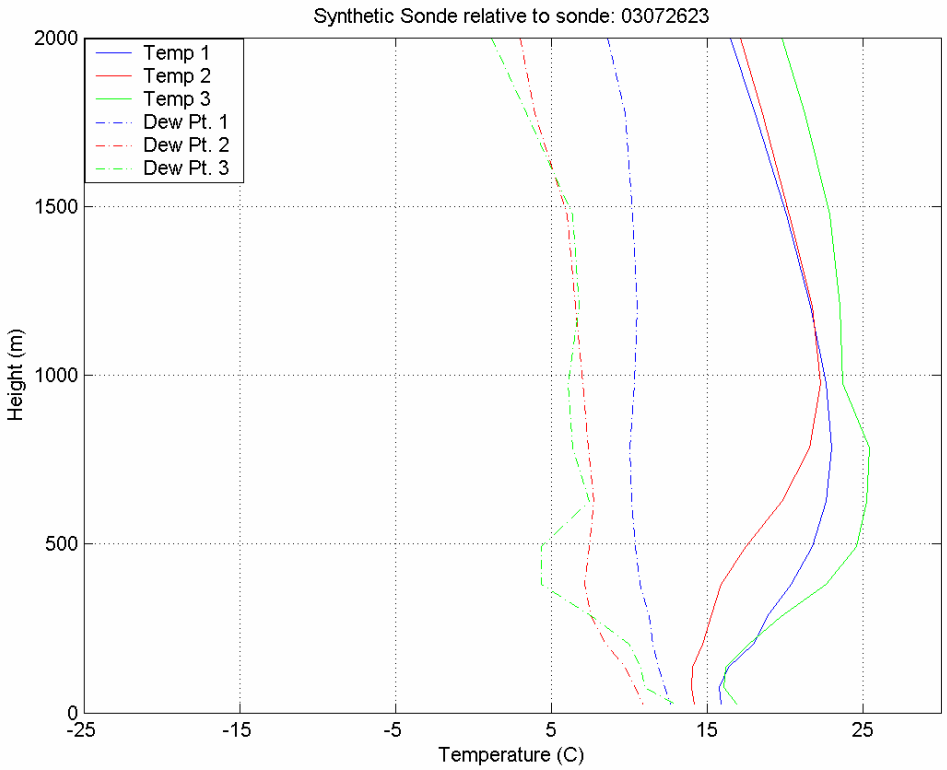

Sonde for 03072623and Model Run0307261200_F012_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25

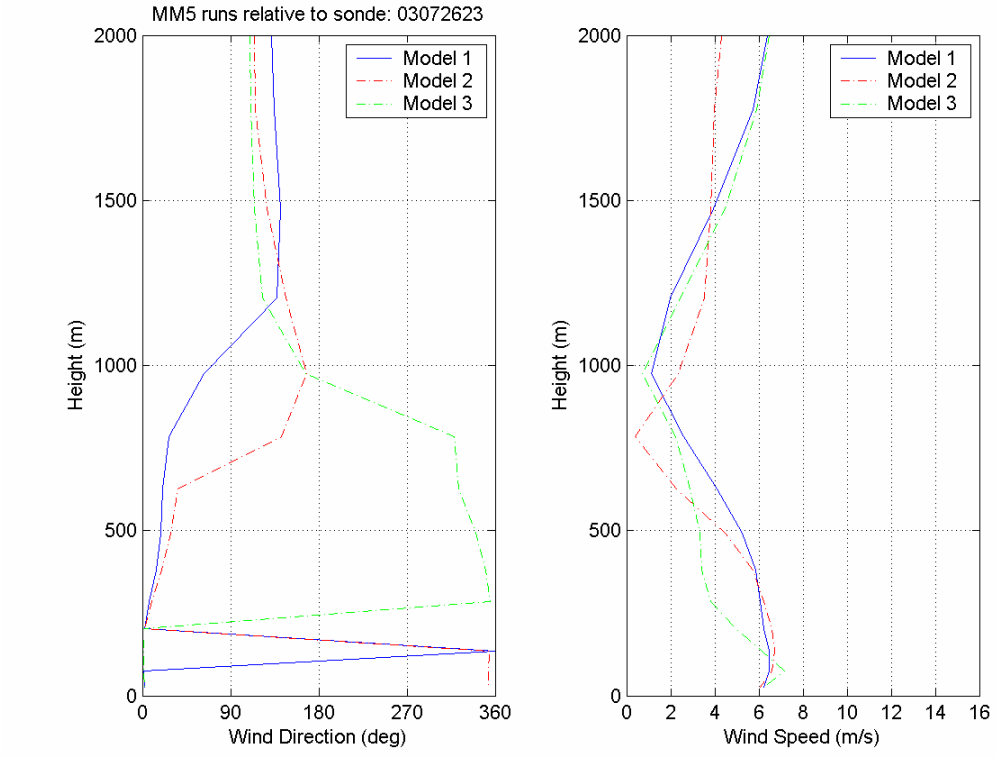

Sonde for 03072623and Model Run0307261200_F012_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
8
10
12
14
16


Sonde for 03072623and Model Run0307270000F000npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25

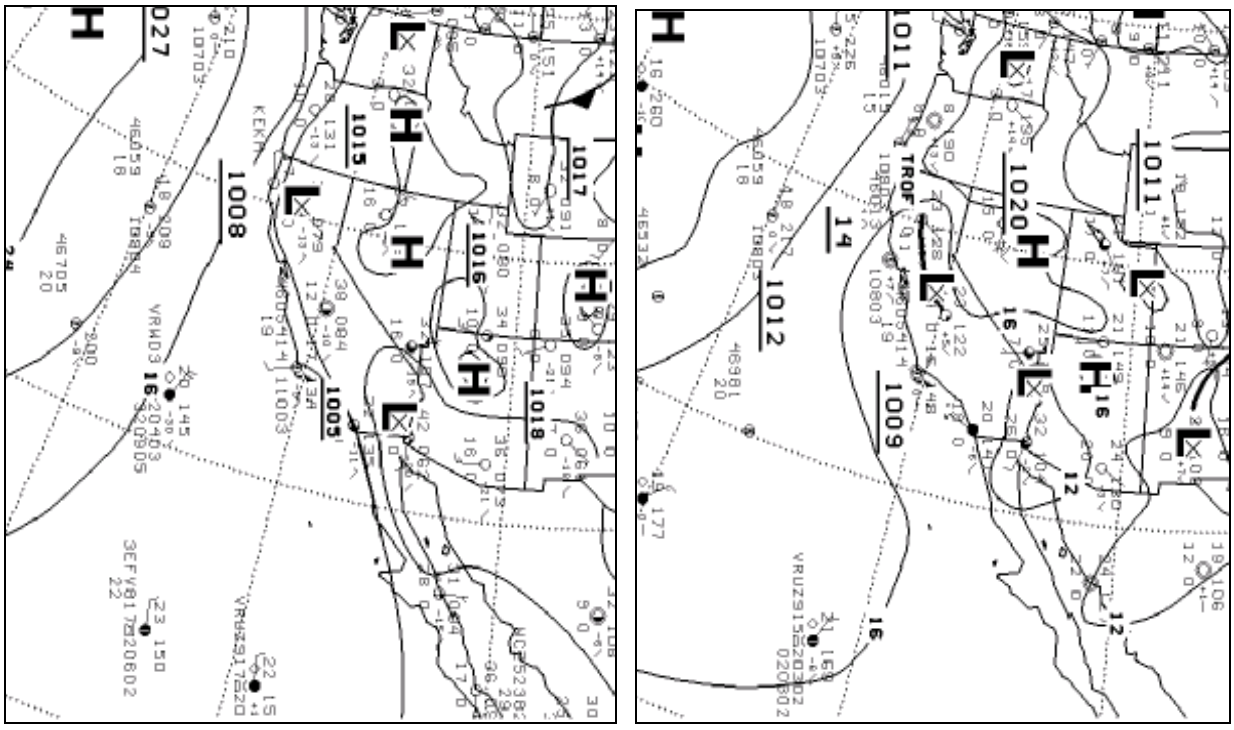

Sonde for 03072623and Model Run0307270000F000npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
8
10
12
14
16

Model Comparison





Synoptic Situation on 26 July

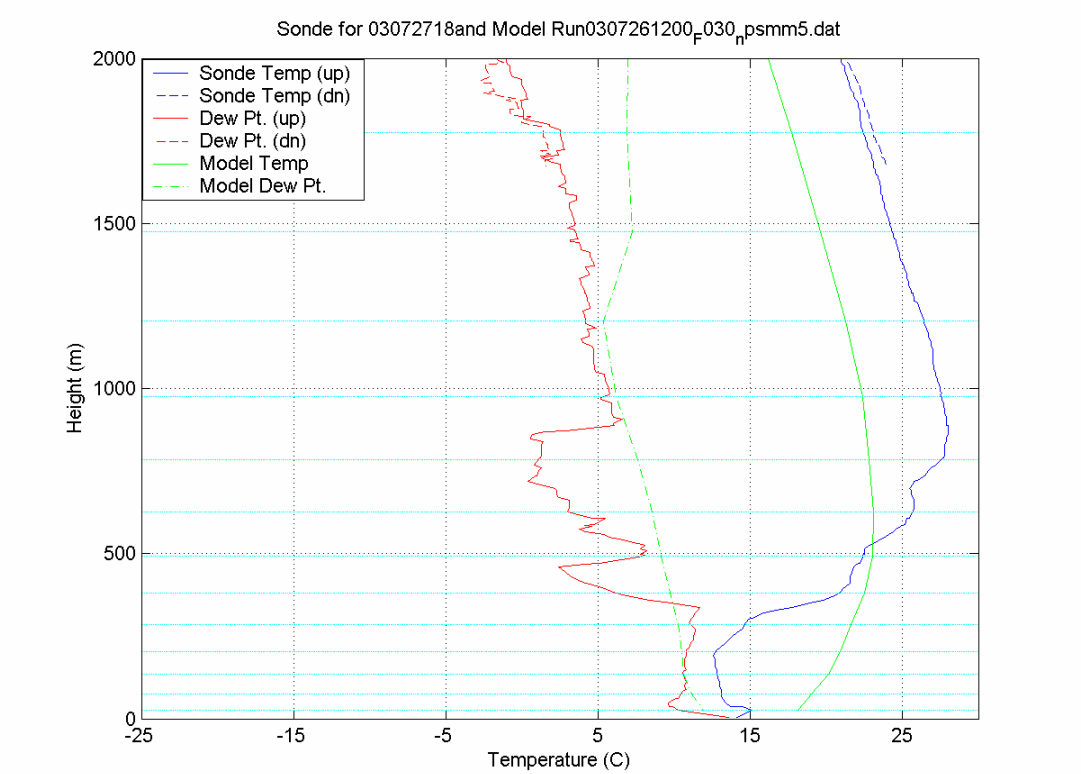


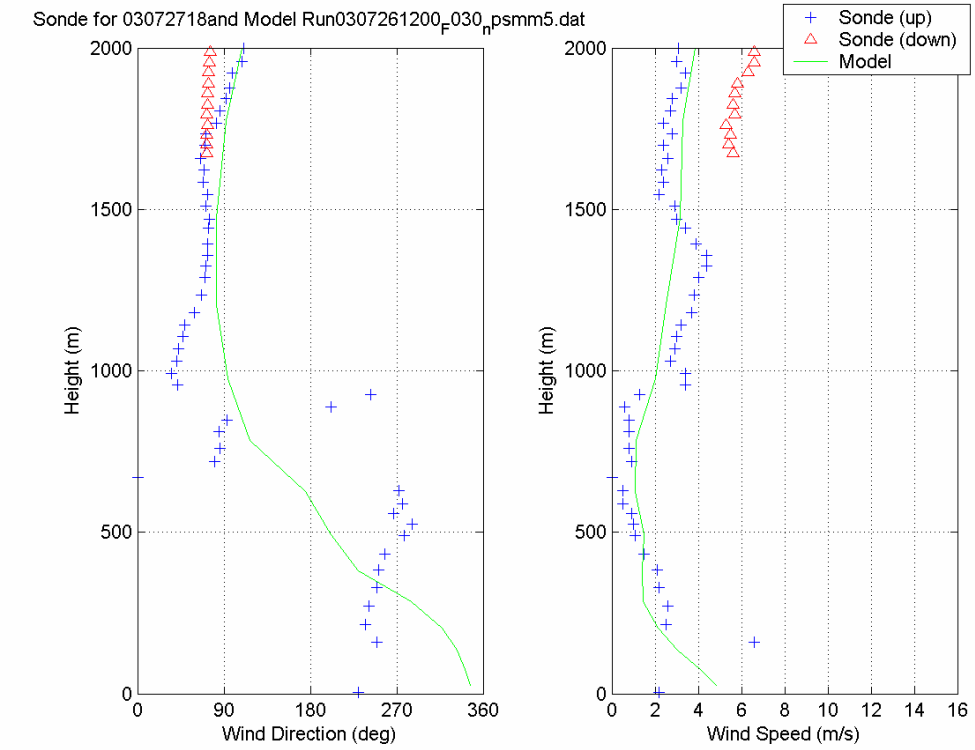
NCEP 00Z and 12Z Preliminary Analysis. Stationary low located over Northern California with associated trough (leeside induced) extending to the south persist. High pressure continues to build to the west later in period.

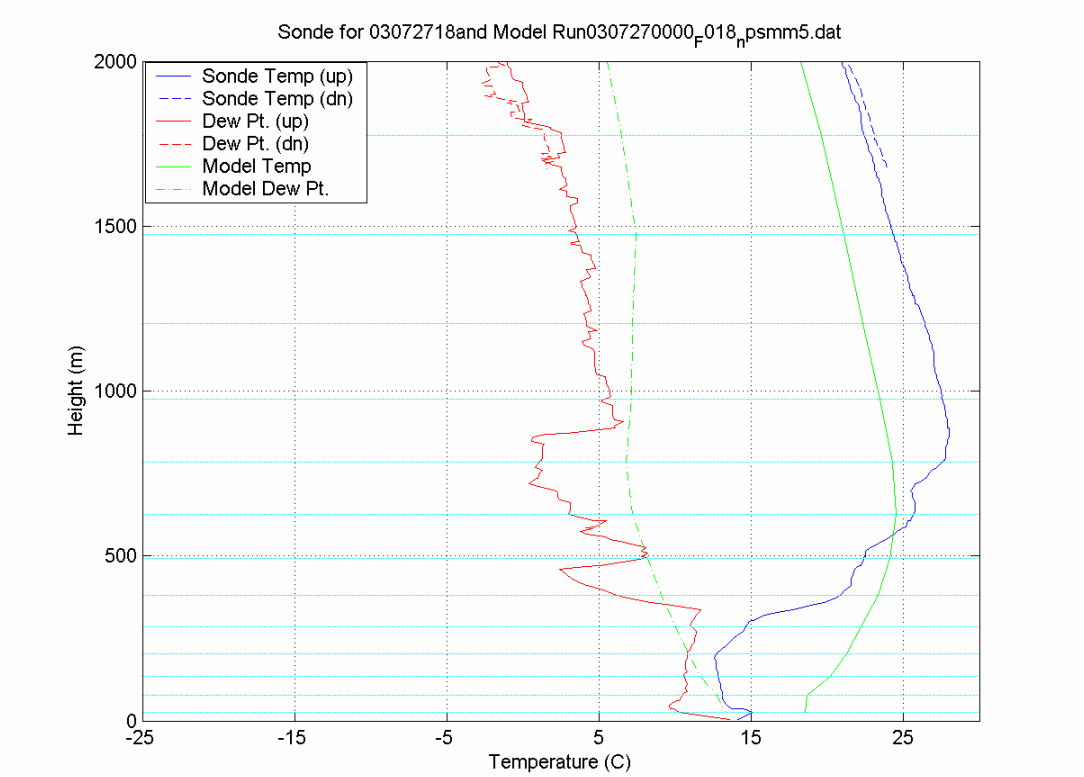
Sonde 18 : I am not convinced F30 shows the inversion at all. If it does it is at the surface. Wind direction is poor with overestimate at the surface and underestimate near 2000 m. F18 show same tendency with low inversion but direction improves until above 1000 m. Wind speeds track well. F06 has good inversion height but shows low temperature above 500 m. Wind directions are 90□out above 1000m.

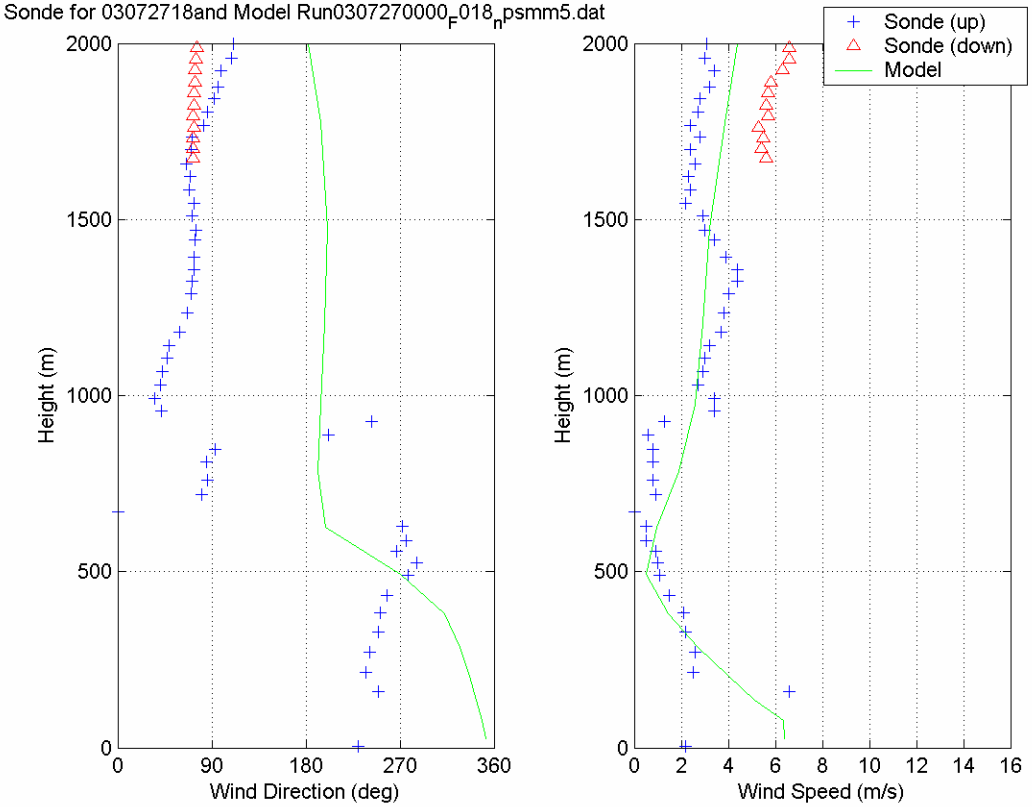
Sonde 19: F24 represents inversion in temp increase only, the dew point temperature is overestimated. Inversion is 200 m lower than observed. Winds are depicted as northerly while actual winds are westerly, winds decreasing with height. F12 shows weak inversion with temperatures being too low above 400 m along with a poor representation o dew point temperature. Winds are still are still out but the speed trend is improving. F00 shows a better inversion structure but still lower than actual. Wind speed and direction is more accurate.

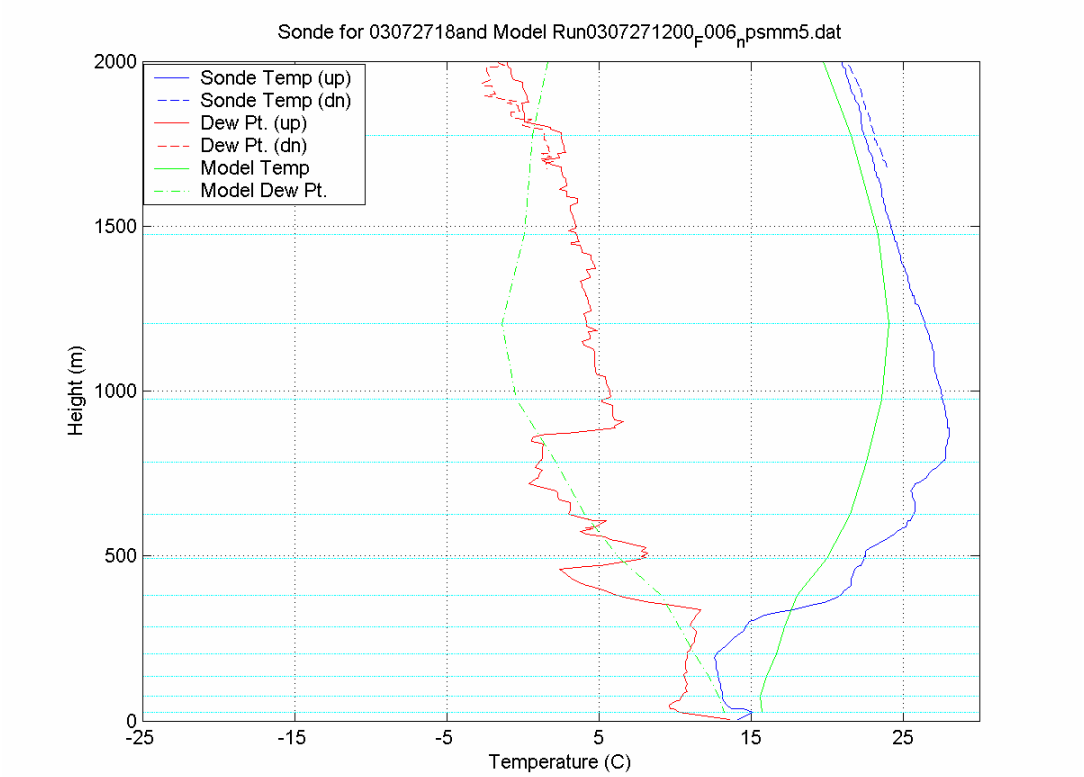
Sonde 22

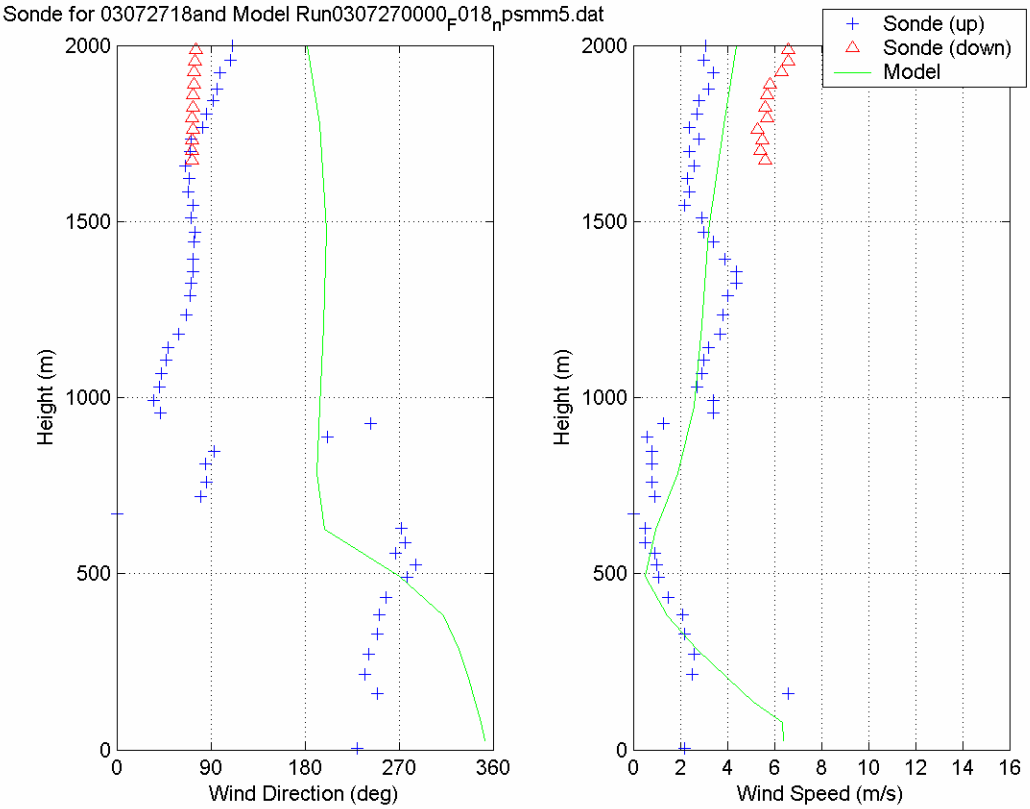

Sonde for 03072718and Model Run0307261200_F030_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072718and Model Run0307261200_F030_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)


Sonde for 03072718and Model Run0307270000_F018_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072718and Model Run0307270000_F018_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
8
10
12
14
16


Sonde for 03072718and Model Run0307271200F006npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072718and Model Run0307270000F018npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
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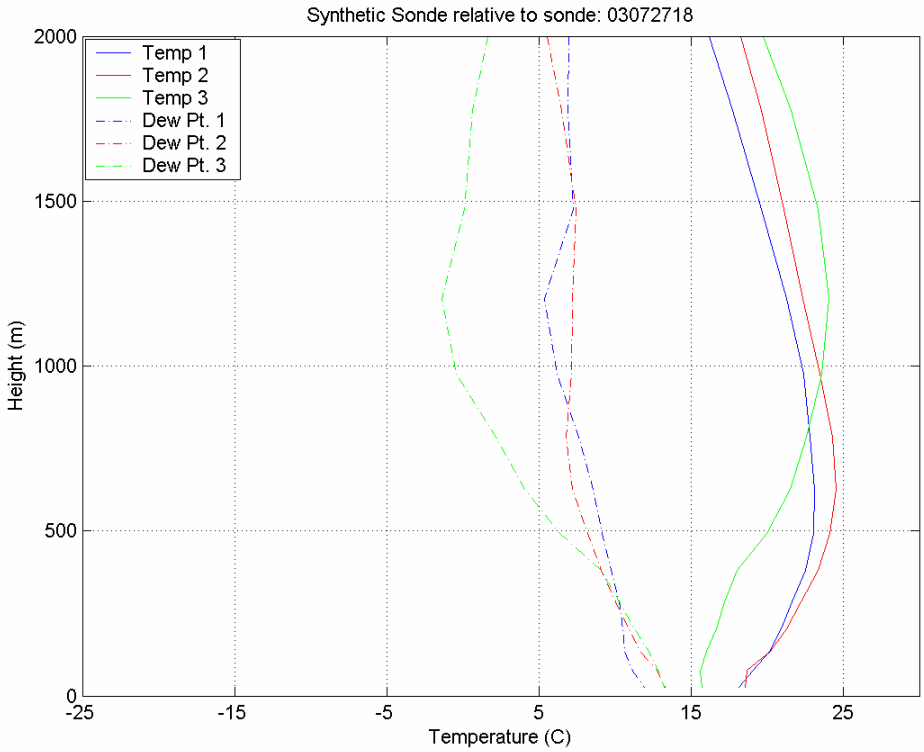
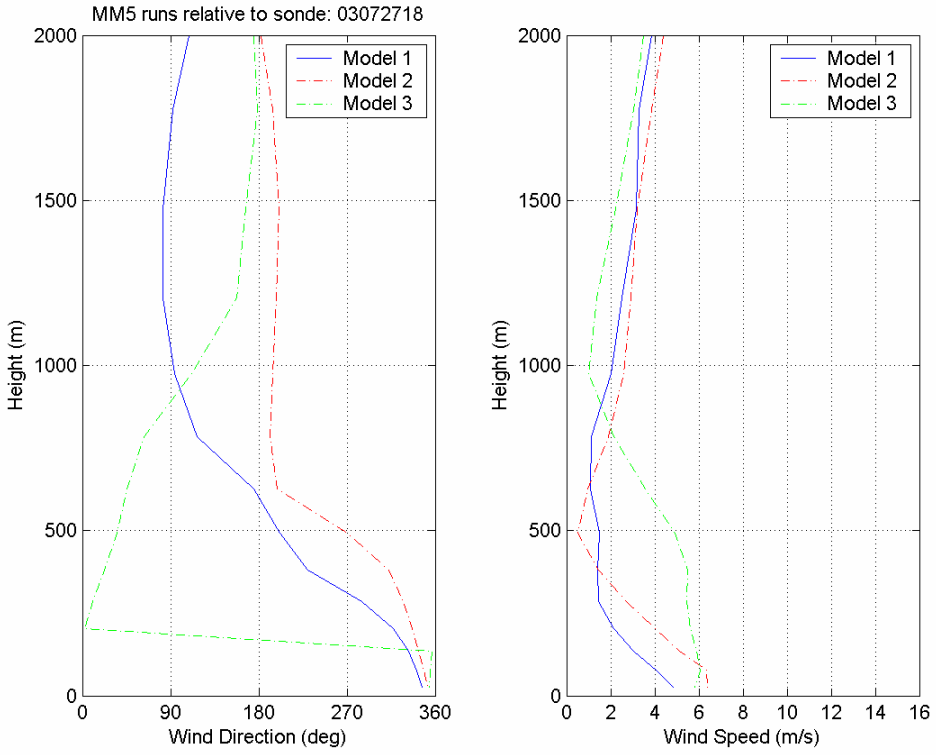
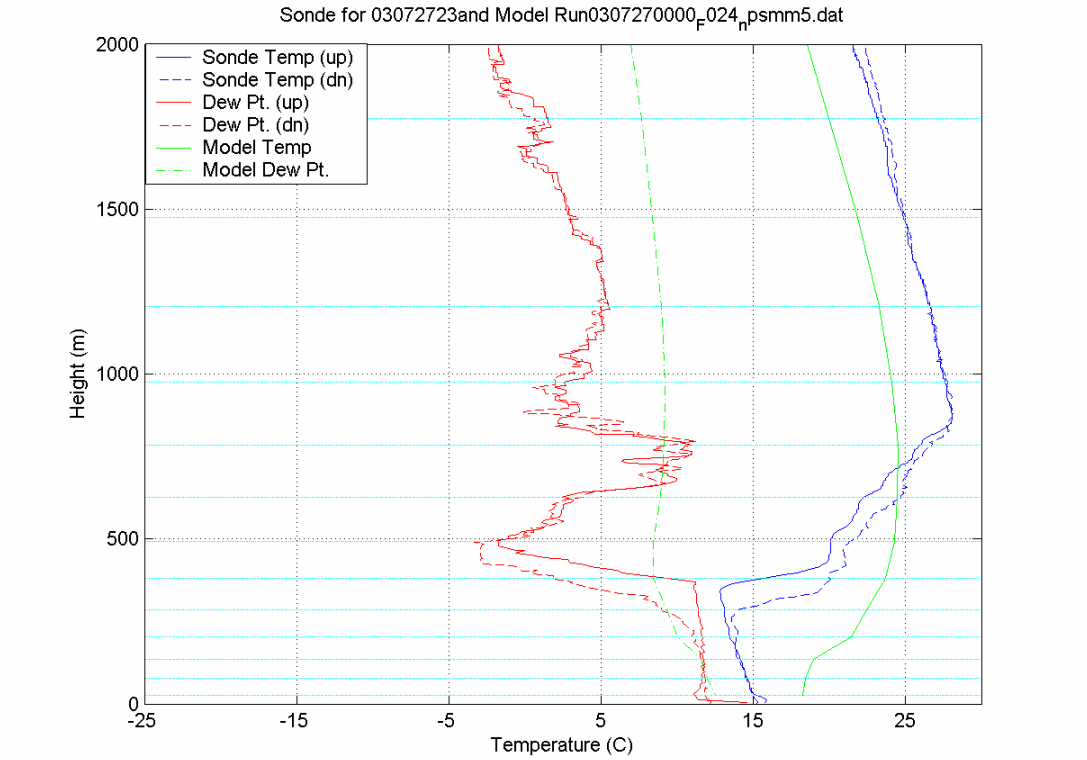
12
14
16

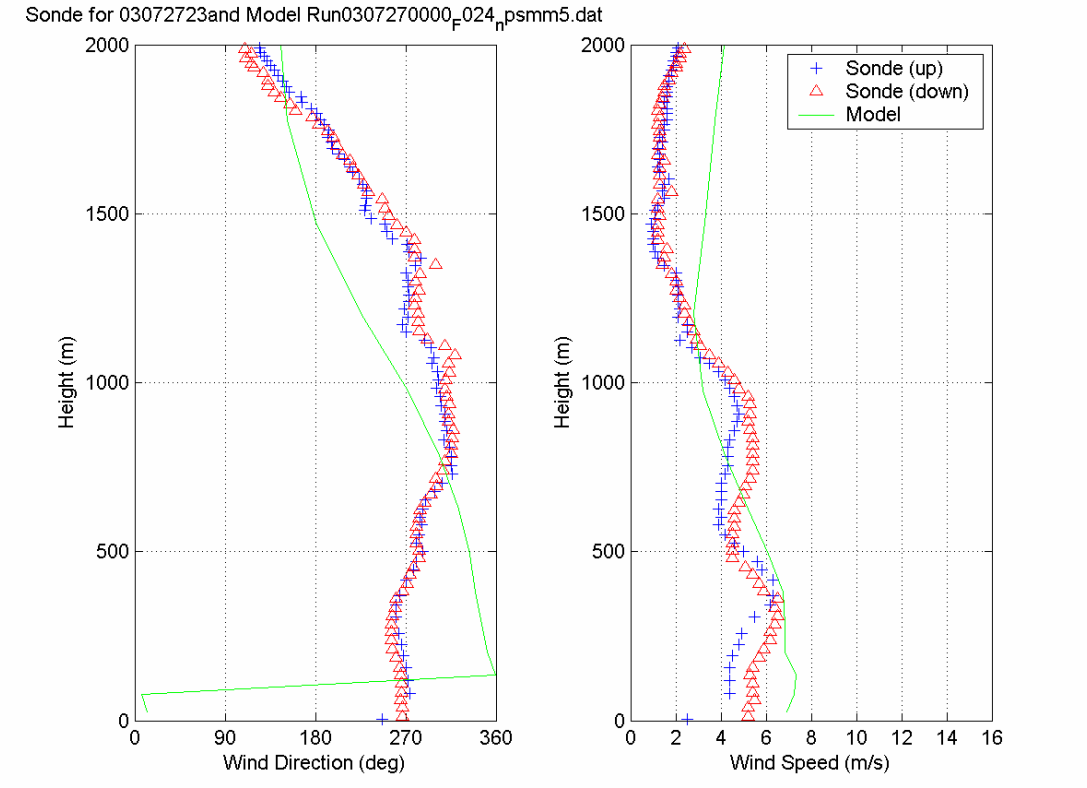
Model Comparison

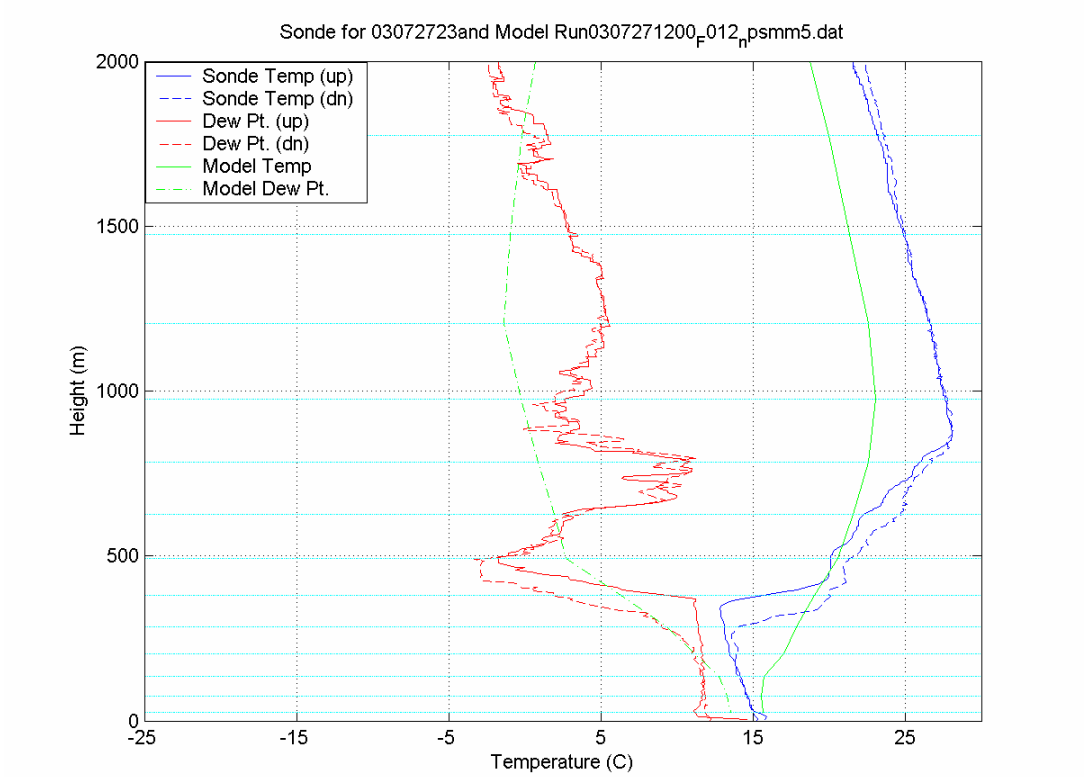


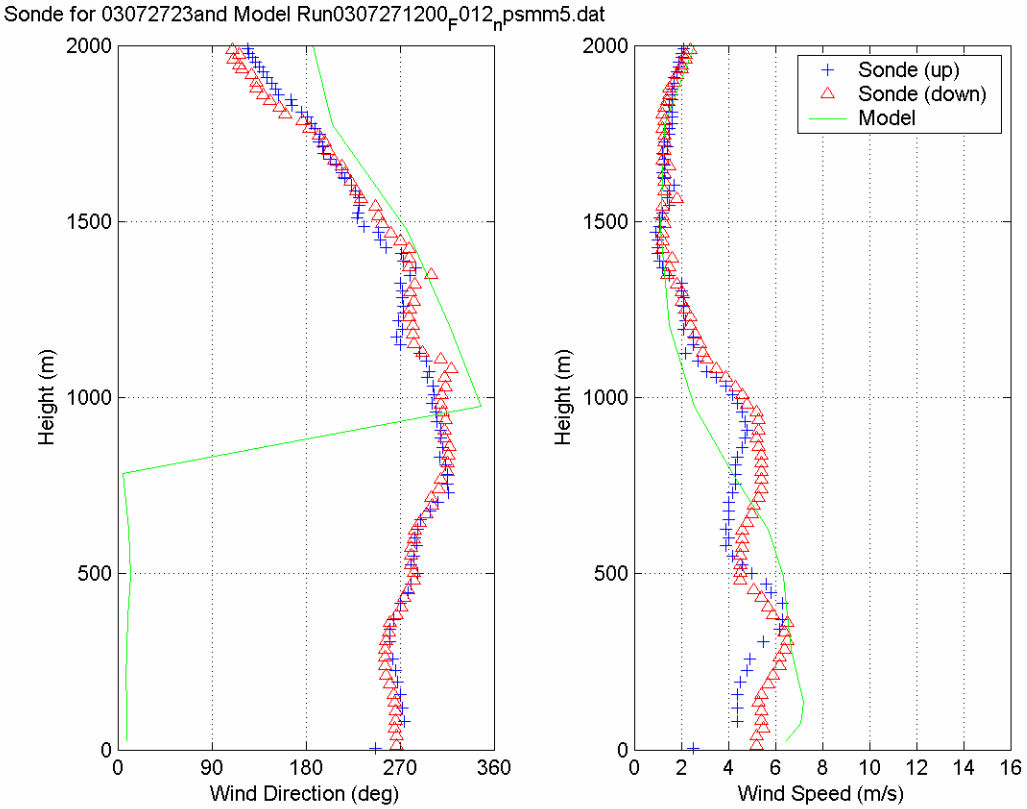


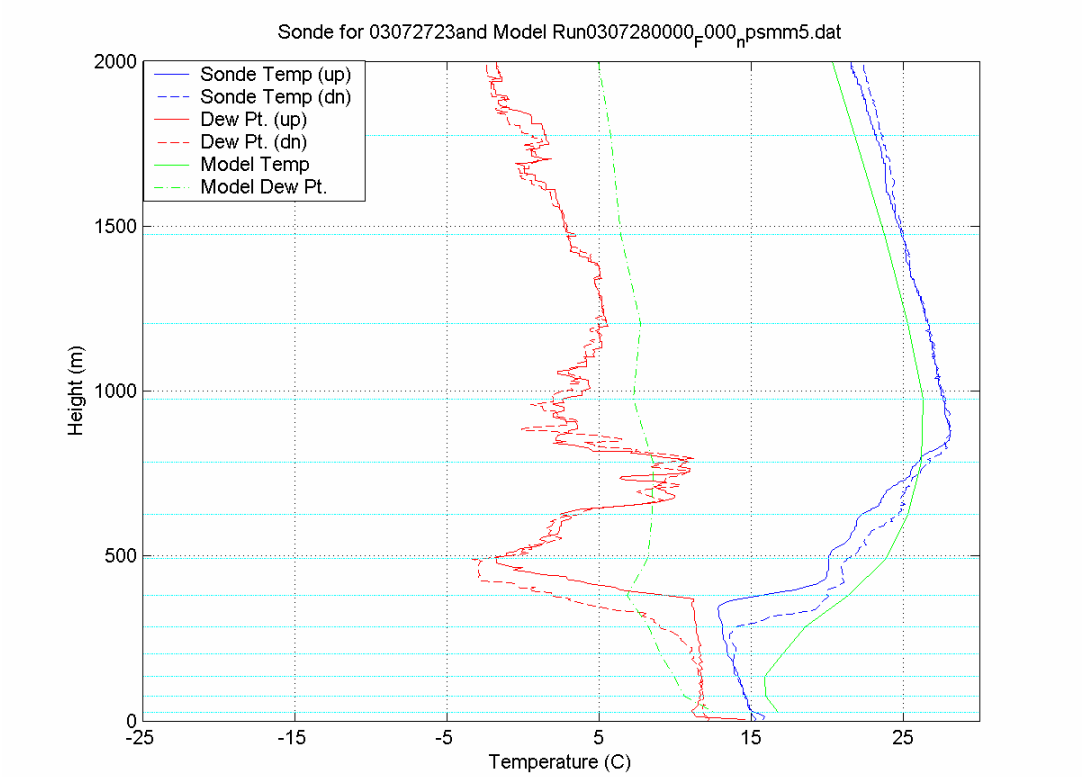
Sonde 23

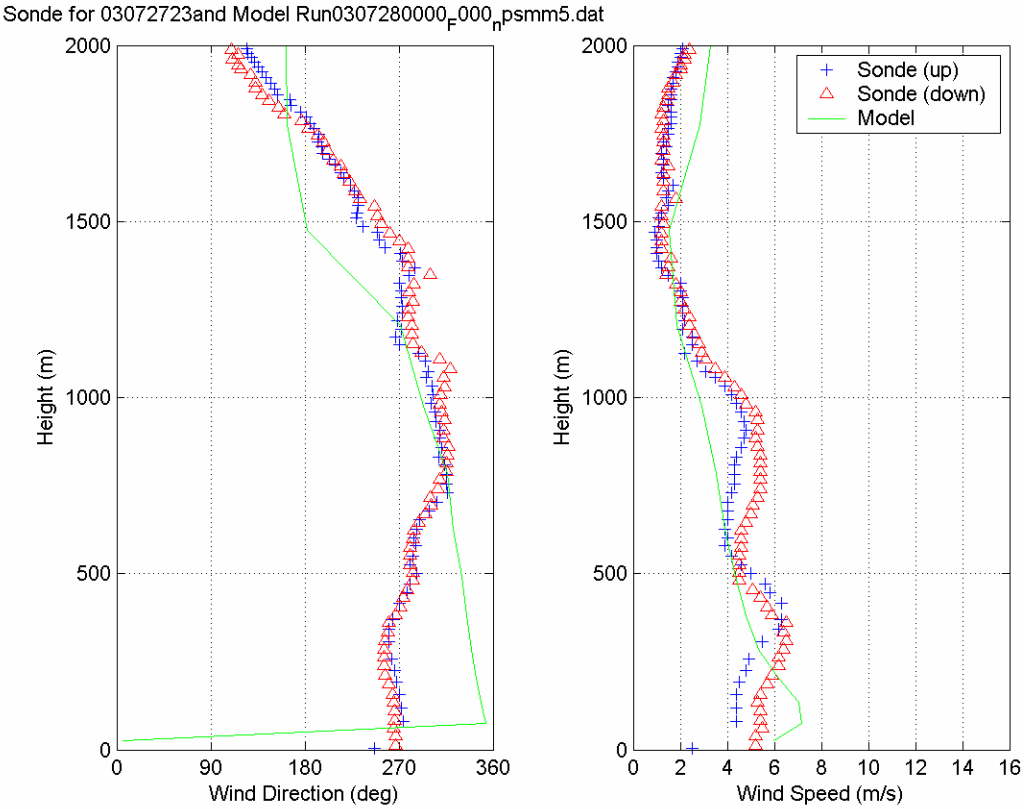

Sonde for 03072723and Model Run0307270000_F024_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072723and Model Run0307270000_F024_npsmm5.dat
Height (m)
Wind Direction (deg)
Sonde (up)
Sonde (down)
Model
Wind Speed (m/s)


Sonde for 03072723and Model Run0307271200F012npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072723and Model Run0307271200F012npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)


Sonde for 03072723and Model Run0307280000F000npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072723and Model Run0307280000F000npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
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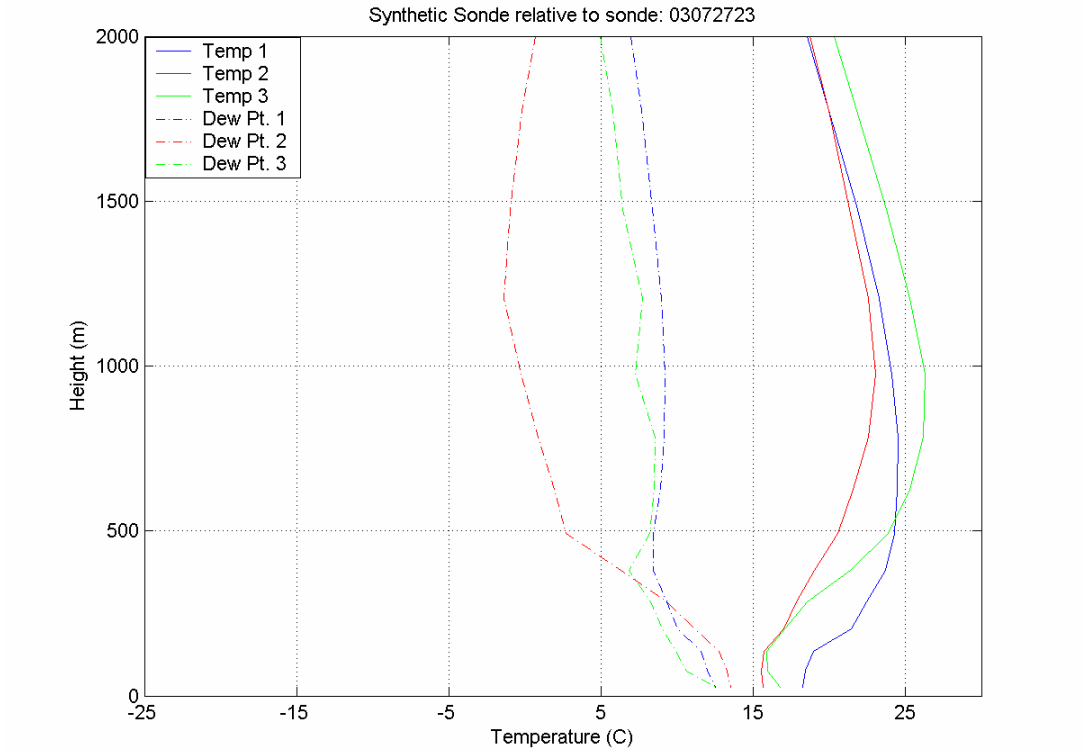
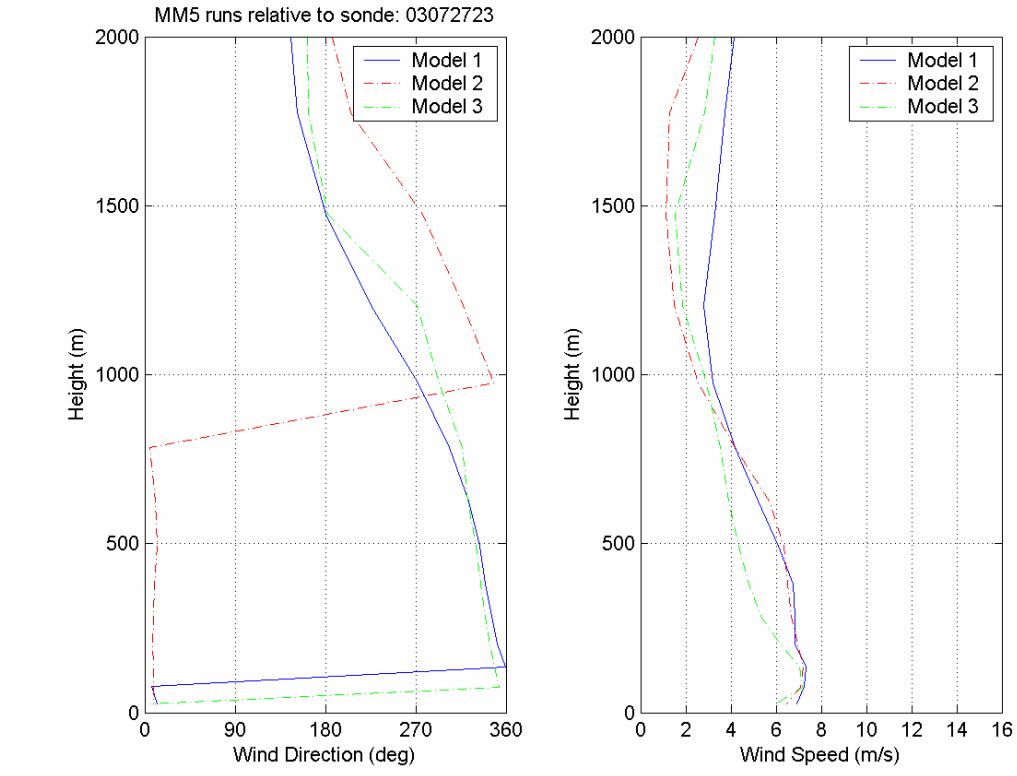
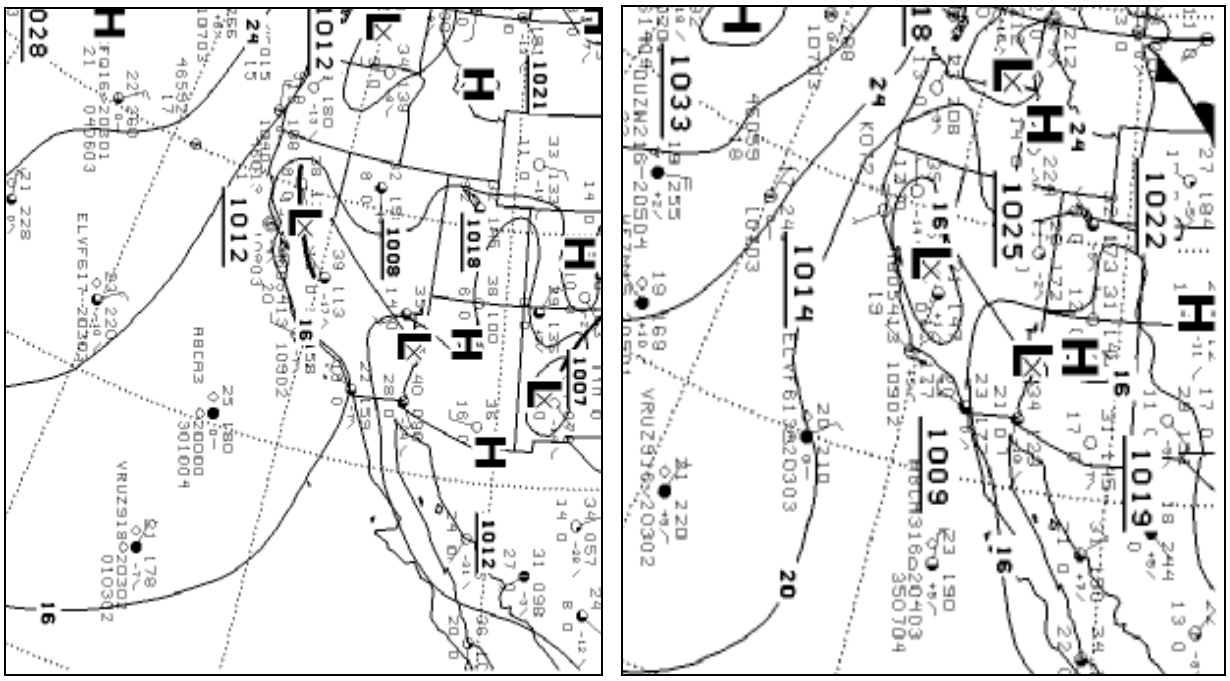
10
12
14
16

Model Comparison





Synoptic Situation on 27 July

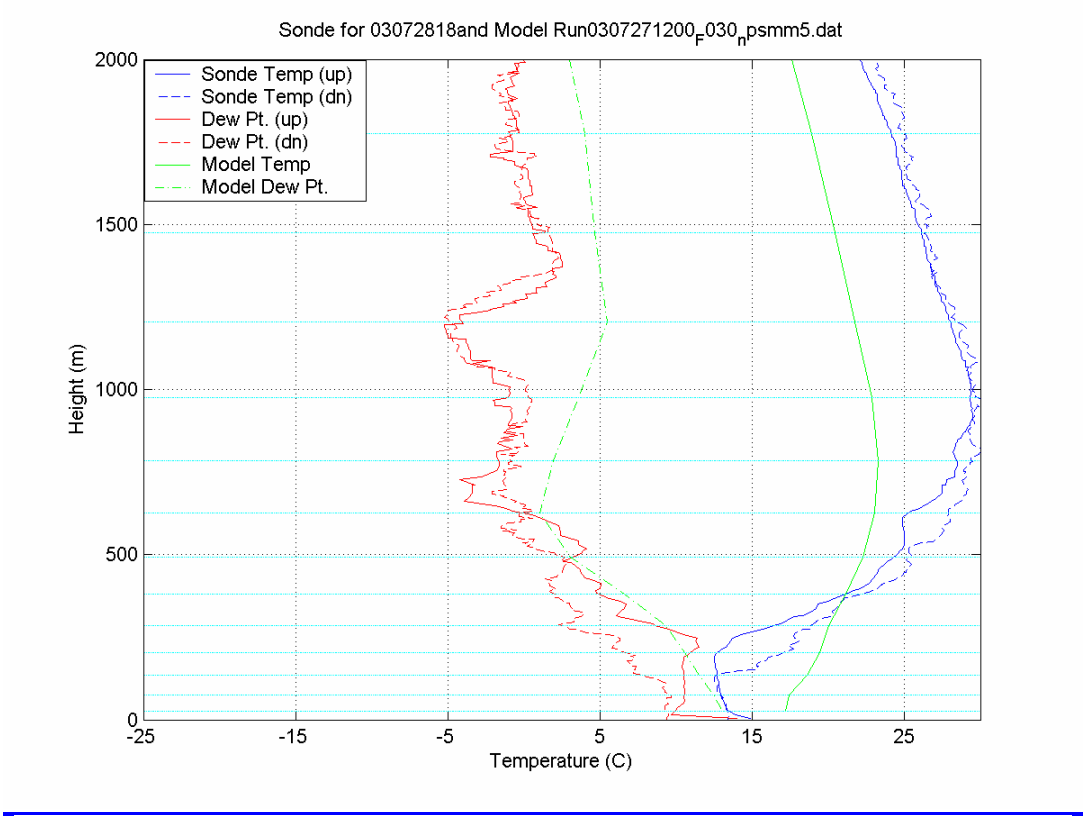


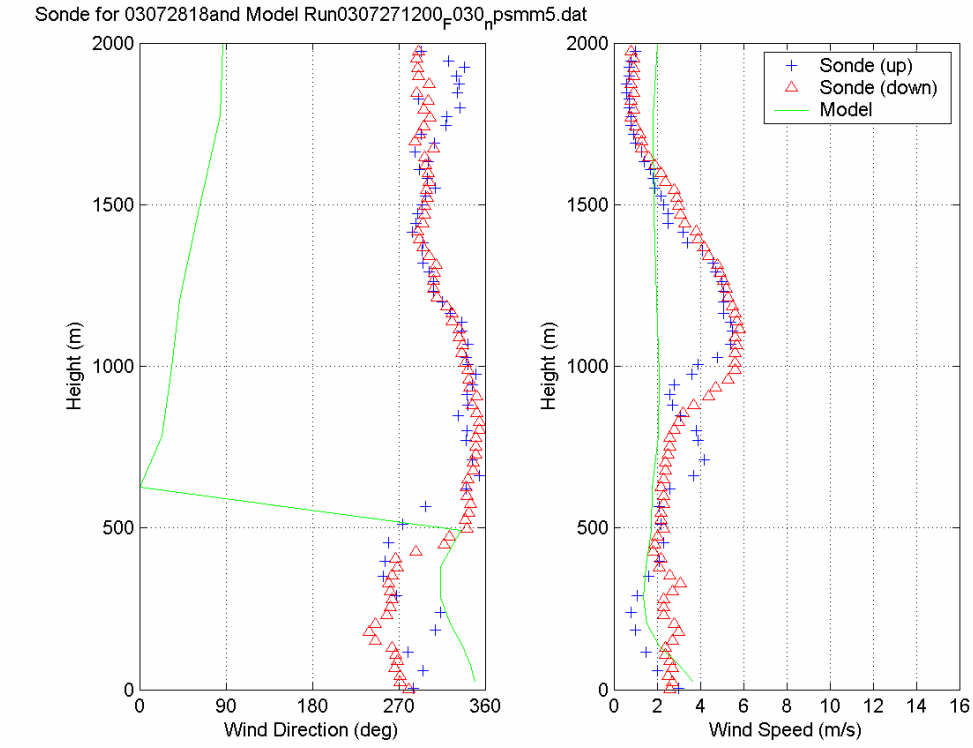
NCEP 00Z and 18Z Preliminary Analysis. Same conditions as previous charts with high continuing to build in from west.

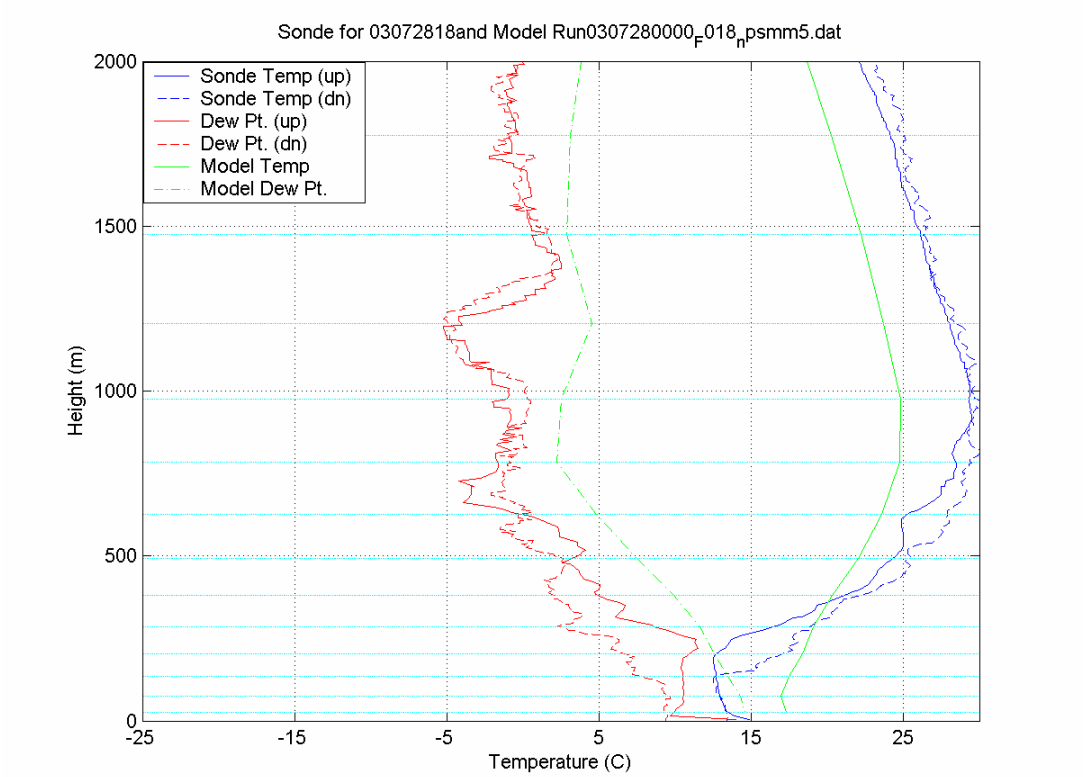
Sonde 22*:* F30 shows a poor inversion structure with temperature low aloft and high close to the surface. Dew point temperature not resolved well. Wind profiles are good considering that the winds are light throughout the column. F18 is similar to F#) with the exception of wind 90□out aloft and speeds too high at the surface. F06 portrays a better structure but still doesn't have a handle on wind direction.

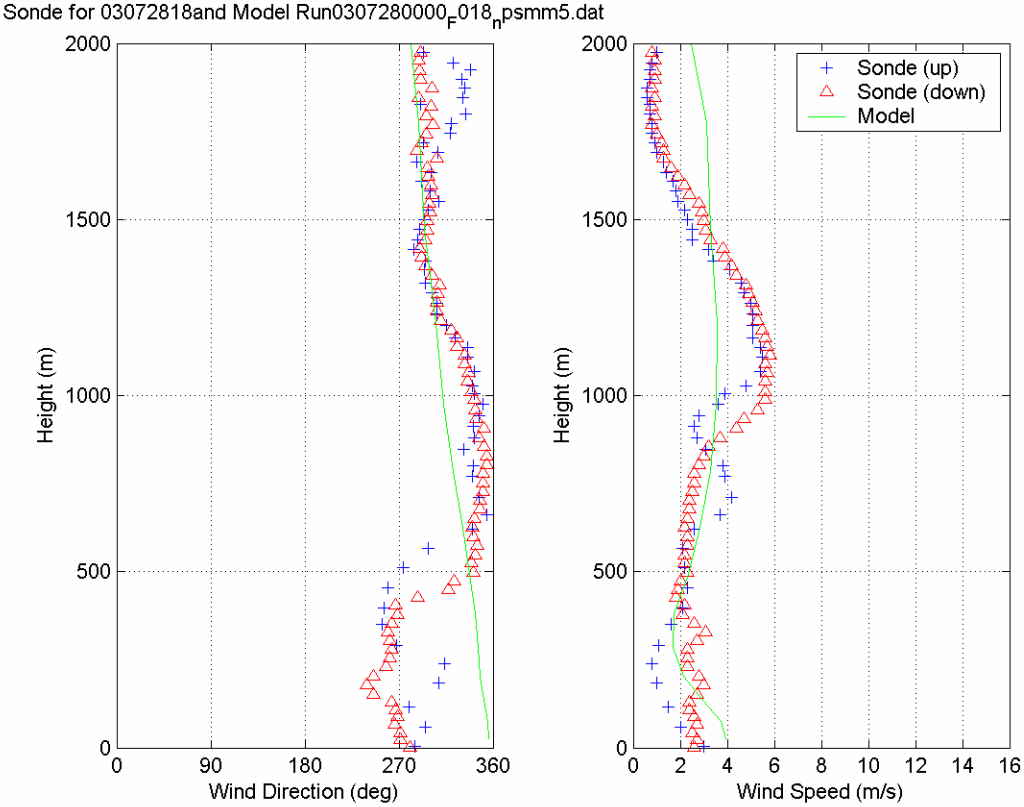
Sonde 23: In F24, the inversion structure is present but 200 m lower than observed. Wind direction is 90□below 300m but gets more accurate with height and tracks speed trend well. In F12 the structure is improving but this run suffers from same direction problem. Temperatures above 500 m are again too low. In F00 the inversion structure seems to get worse due to the dew point temperature profile. Direction consistently out of phase below 500 m.

Sonde 24


Sonde for 03072818and Model Run0307271200F030npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)


Sonde for 03072818and Model Run0307271200F030npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)


Sonde for 03072818and Model Run0307280000_F018_npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072818and Model Run0307280000_F018_npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
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6
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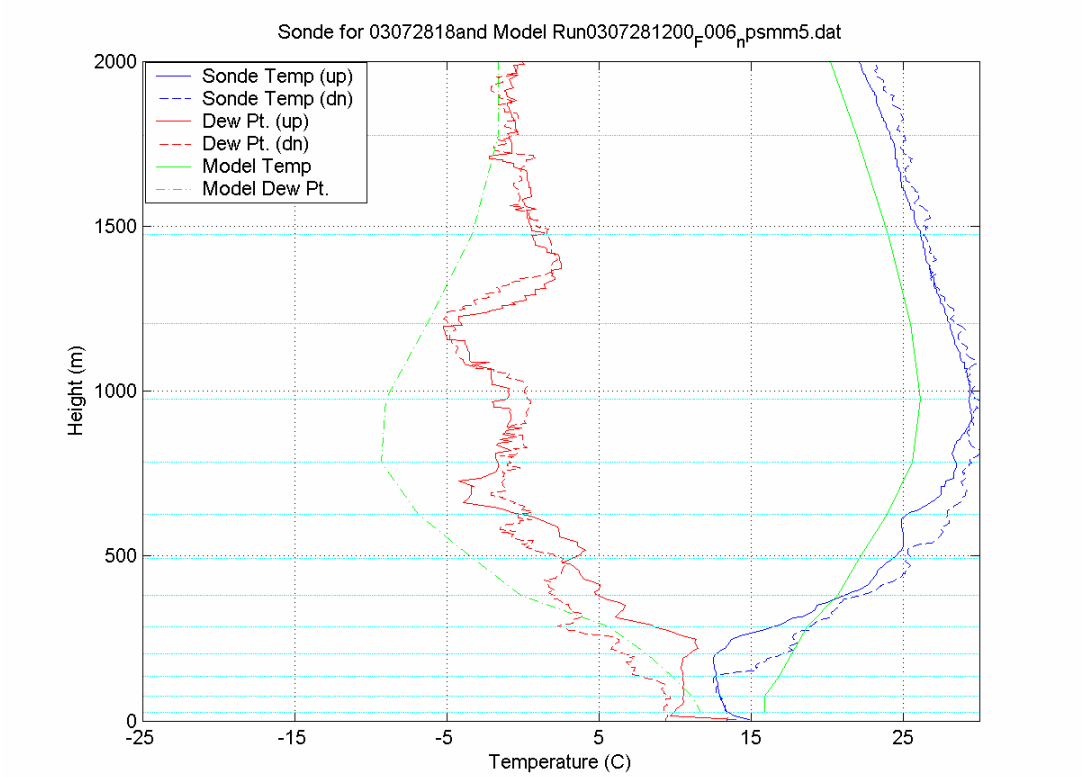
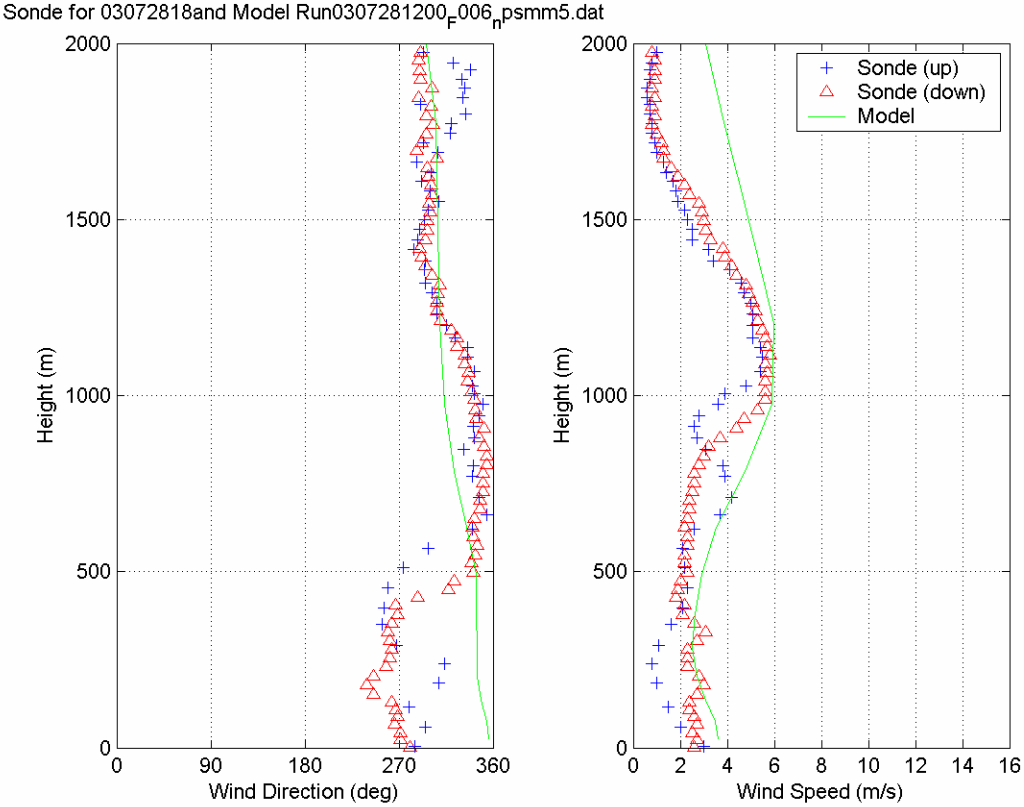
12
14
16


Sonde for 03072818and Model Run0307281200F006npsmm5.dat
Sonde Temp (up)
Sonde Temp (dn)
Dew Pt. (up)
Dew Pt. (dn)
Model Temp
Model Dew Pt.
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


Sonde for 03072818and Model Run0307281200F006npsmm5.dat
Sonde (up)
Sonde (down)
Model
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
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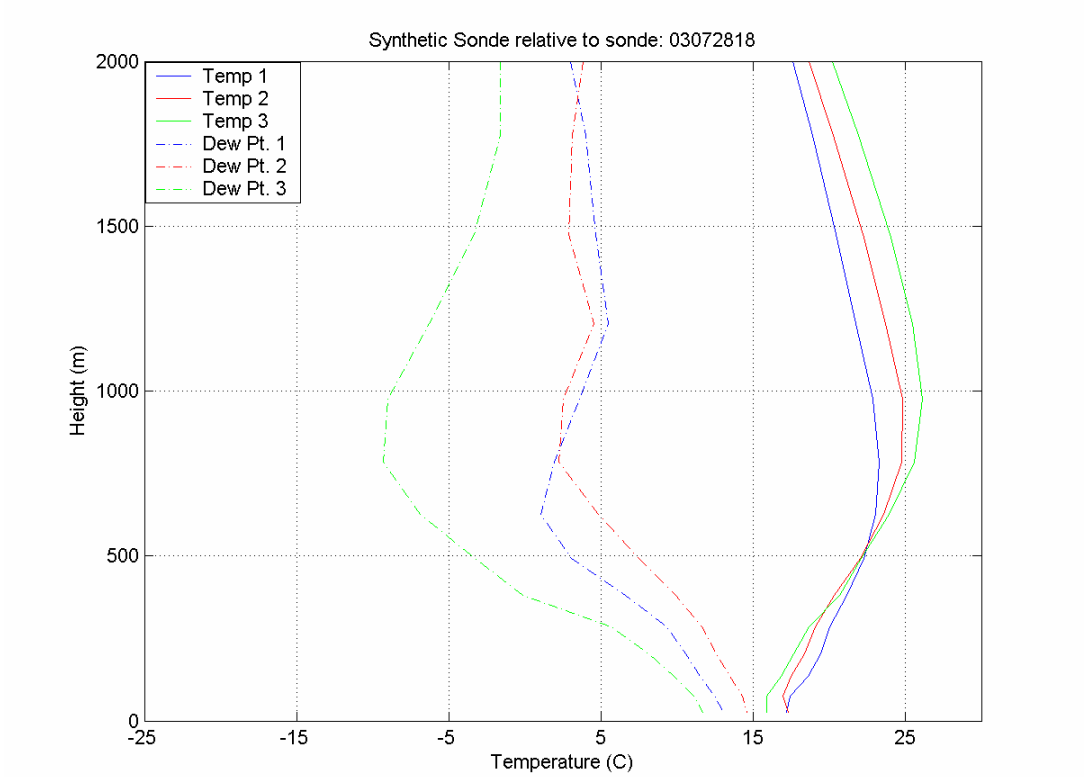
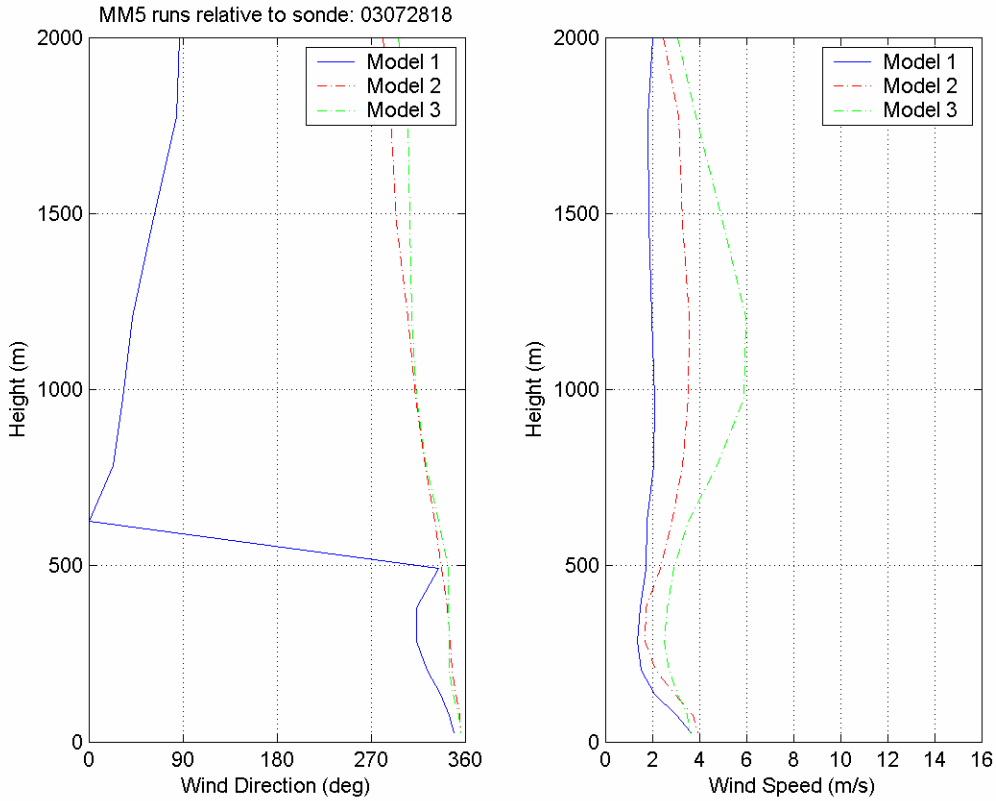
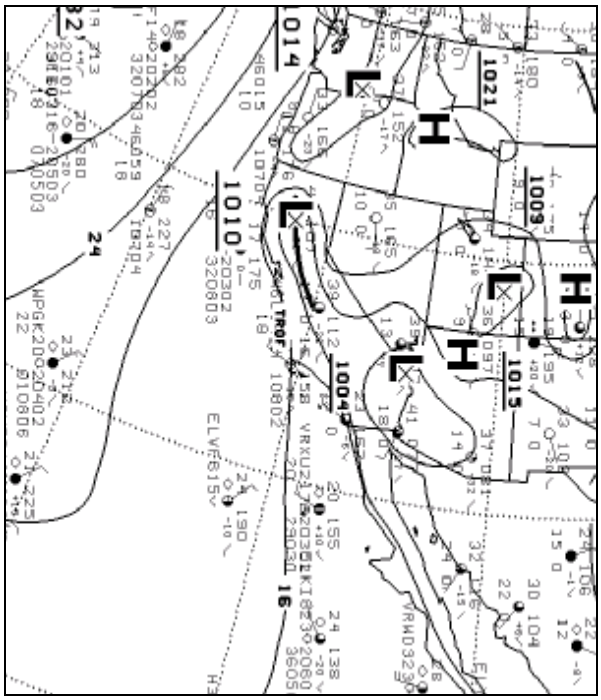
8
10
12
14
16


Synthetic Sonde relative to sonde: 03072818
Temp 1
Temp 2
Temp 3
Dew Pt. 1
Dew Pt. 2
Dew Pt. 3
Height (m)
Temperature (C)
2000
1500
1000
500
0
-25
-15
-5
5
15
25


MM5 runs relative to sonde: 03072818
Model 1
Model 2
Model 3
Height (m)
Wind Direction (deg)
Wind Speed (m/s)
2000
1500
1000
500
0
0
90
180
270
360
2
4
6
8
10
12
14
16

Synoptic Situation on 28 July



NCEP 00Z Preliminary Analysis. Same conditions as previous charts with high from west slightly weakening.

Sonde 24: F30 defines the inversion structure but remains lower than observed. Wind direction is consistently off with speed not tracking as well as has been the case. F18 shows an improvement in the structure but the typical problems with low temperature continue. In F06 the structure becomes more apparent, though slightly dryer aloft. Wind direction is not resolved well at the lower levels.

Conclusions

Considering the stability of the synoptic patterns, this case provided a unique opportunity to focus on the mesoscale influences and MM5s ability to simulate the coastal/marine environment. Throughout the period that this research was conducted, synoptic variability was minimal as confirmed by the observations that recorded relentless overcast conditions for the 4 days of the 2nd leg.

Beginning with *Sonde 16*, this case demonstrates the importance of understanding the model grid location. For the given latitude and longitude of the sonde launch, the model returned a temperature profile for a grid point that was obviously located over land as indicated by the height at which the lowest level of the model was resolved (≈ 200 m) vice the expected 30 m initial height. Without having a vertical profile of the area, it would be easy for an observer to misinterpret the model fields in a horizontal depiction of this area. Even with a relatively high resolution of 12 km, this interpretation problem is worthy of concern.

The trends observed in analysis of forecast verse sonde data were fairly consistent. Forecast beyond 12 hours typically represented the marine inversion being much lower than actual observations and in some cases, run for Sonde 18 for example, resolution of the feature was questionable. Temperatures where typically too high at the surface (≈ 2˚ C) below the inversion and became too cool above the inversion (≈ 2˚ C), the run for Sonde 19 shows this well. Also on the run for Sonde 19, the dew point temperature is abnormal in that it does not depict the inversion well. Wind direction showed a trend for being 90˚ out from observed winds. Since the synoptic picture doesn't seem to indicate

any reason for this occurring, it does imply that a mesoscale influence that the model was unable to resolve were most likely the cause of this discrepancy. In the cases where easterlies were forecast but southerlies were observed, interaction with the coastal mountains may influence the model but terrain resolution makes it impossible to simulate. Wind speeds trended well for the most part but it was noted on several occasions that surface speeds where 2-4 m/s faster than those observed. Model runs for 6 hour forecast and less consistently showed better inversion structure while typically resolving inversion heights more accurately. Still, the wind speed and wind direction problems addressed above persisted in these forecast and analysis as well.

Overall, although MM5 made a valiant effort to forecast these persistent conditions, this analysis shows that the course vertical resolution coupled with its inability to resolve a mesocsale disturbance in the vicinity limited its success. One possible fix is to increase resolution but only in conjunction with better terrain resolution and lateral boundary conditions. Also it seems apparent that the boundary layer physics hamper the models ability to resolve low-level conditions to a greater degree of accuracy.